Proceedings of the
CARNATION CREEK WORKSHOP, A 10 YEAR REVIEW

G. Hartman, Ed.

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February 24-26, 1982
Malaspina College, Nanaimo, B.C.

PROCEEDINGS
OF THE CARNATION CREEK WORKSHOP:
A TEN-YEAR REVIEW

G.F. Hartman, Editor

Pacific Biological Station
Nanaimo, B.C.
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Malaspina College
Nanaimo, B.C.

February 24 to 26, 1982

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PREFACE

The Carnation Creek Watershed Project was started in the summer of 1970. At the time of this workshop, 11 years of the project were complete. The project was planned to be carried out in three 5-year phases—prelogging, logging, and postlogging. The logging phase has been complete for less than one year. The watershed is still responding to the logging treatments, and it is anticipated that it will continue to do so.

In spite of the expectation that the most significant part of the results might be derived from the last 5 years of the study, it was considered to be worthwhile to hold a 10-year review meeting. There has been widespread interest in the project for many years.

When this meeting was organized, it was planned with the intention of reporting general progress and exposing major results, to date, to an audience with heavy management representation. The working group in the project has been particularly anxious to get feedback from resource management people, particularly foresters, fisheries people, soils workers, and hydrologists. Such response was considered important for making the last few years of the work most effective.

It must be recognized that many of the papers in these proceedings report results to date. All information is not yet in and interpretations made by some authors may change. Some of the work (e.g., the revegetation studies) will carry on for many more years. Some of the student research projects are not complete.

The results from a meeting such as this one may be most valuable if managers use the information to help themselves understand important components of watershed processes. It will be necessary for managers to depend on their own experience to relate what is understood about Carnation Creek to other systems that may be different.

The results in the proceedings from this meeting show that there is a sprectrum of impacts from different phases of the logging process. The impacts are not necessarily all negative to fish production. This project will be most useful if managers can make the most of potentially positive effects and minimize those that are negative. It is clear that it is easier to say this than do it. The success of the Carnation Creek study will be measured by how much it assists people in balancing impacts in the planning process.

The question and answer sections were transcribed from tapes. The tape recorder did not pick up all the questions or answers clearly. Some questions and answers are unfortunately not included. The editor has also taken some liberty to rephrase the discussion material because sentences were incomplete or awkward. If what you are indicated as saying does not agree with your recall of your comments, please accept editorial apology. Some of the questions that arose at the end of the meeting were short, stood alone, and pertained to specific papers. In many cases, these questions have been moved so that they follow the appropriate paper.

ACKNOWLEDGEMENTS

A great number of people have been involved in the Carnation Creek study. Anyone who has helped is gratefully acknowledged. It is not unusual to go to a Fisheries meeting and encounter several people who did their first field work at the project. Some people have put years of their lives into the study. Although they may be authors or coauthors in these proceedings, they should still be thanked. Bruce Andersen, R. Leahy, Phil Neaves, Charlie Scrivener, Tom Brown, R. Keene, A. Von Finster, J. Lamb, and Don Sutherland have all made outstanding contributions to the work.

Dave Narver was one of the primary founders of the study. It is a tribute to his judgement that the directions that he perceived as important 12 years ago are the ones that led to useful answers now.

The members of the Coordinating Committee who have guided the project have played a vital role. MacMillan Bloedel Limited have played an active and positive part in the project during and since its start. In times of difficulty, they came through with financial support.

In organizing the meeting of February 24 to 26, 1982, Dr. E.D. Lane and Dick Isaacson were very helpful. They, along with the following Malaspina College students, made the meeting run smoothly. Doug Bifford, Jan Brouwer, Elizabeth Cameron, Joel Clegg, Gary Duccomun, John Fredrickson, Paul Gibson, Kathy Lysack, Jamie Moan, Murray Rudd, Mike Turner, and Allen Vieaux worked hard during the meeting.

The theater faculty, Neil Rutherford, students, the cook-training staff, and Mr. Henri Dane were all extremely helpful. We appreciate their assistance and cooperation and the opportunity to use the Malaspina College facilities for the meeting.

Roy Crawford and John Wiens provided a great deal of assistance on the technical work in preparing the printed proceedings.

Bonita Baker put in a great many hours typing these manuscripts and setting them up in this publication format. Her energy and enthusiasm in carrying out such a large task are appreciated by all the contributors to these proceedings.

Finally, working group members who put such effort into preparing papers for these proceedings deserve special thanks. Without their efforts in the meeting and in the field, the project would not exist.

We thank Diane Paxton for designing and preparing the cover.

WELCOME

Good morning, ladies and gentlemen. First of all, on behalf of our college administration, faculty, staff, and students, it is a great honor and pleasure for me to welcome all our guests and participants to Malaspina College and to this Carnation Creek forum.

This project is of particular interest to me because of the nature of the study which has involved so many people from industries, colleges, and universities. I would especially like to thank Dick Beamish and his staff at the Biological Station. As you may know, our college has a tremendous history, especially in terms of forestry, logging, and logging-related programs and now in biological and specific issue programs such as our fish culture program under the direction of Dave Lane.

By way of introduction for you today, you should realize that there are some 170 community colleges in Canada, of which 21 colleges and institutions are in British Columbia. All colleges have experienced a very rapid growth in the last 10 years in all categories—that is, academic, technical, career, and vocational.

It looks as if our growth in the next 10 years will certainly be in the technologies, trades, and community vocational fields. As some of you may recall, the Nanaimo Vocational School was the first of its kind in B.C. and opened its doors back in 1936. The first two programs were carpentry and automotive. In 1956, we added other forest-related courses such as heavy equipment operating, welding, and logging. In 1969, the Nanaimo Vocational School melded with Malaspina College and became Vancouver Island's first community college. Our campus is now located on approximately 165 acres in Nanaimo, with satellite campuses at Powell River and Duncan.

We now offer over 100 programs with approximately 4 000 students in vocational, 2 200 in academic, and some 10 000 students in community educational programs. The philosophy of our college is organized for teaching, not for research, although research is a very important factor in education and of much interest to us, as witnessed by today's forum. We would like to stress the practical side of our training, with strong emphasis on good work habits and personal responsibility. We pride ourselves on being innovative, utilizing new teaching techniques, and being flexible and responsible to community needs. During the last few years, we have observed great strides toward the improvement in communications and intergovernmental cooperation in providing for additional and innovative programs such as energy systems and fish culture, and you may have heard about our future plant and greenhouse technology program.

This now leaves me with the introduction of someone who has given a great deal of support to Malaspina College, to our students and staff cooperative educational program in Fisheries, and to other mutual projects. I would now like to introduce Dick Beamish who is the Director of the Biological Station in Nanaimo.

R. Johnston
President
Malaspina College
Nanaimo, B.C.

OPENING COMMENTS

As Director of the Resource Services Branch, I would like to begin by making a brief comment about my own job. One of the things I do is try to ensure that our staff have adequate support for research. I feel the best way I can do this is to make certain that the projects that we engage in are relevant to fishery problems and sound scientifically. One of the most relevant problems in Fisheries in Canada today has to do with the effect of alteration of habitat on some fish stocks, and one of the most relevant projects we have in Fisheries in Canada is the Carnation Creek Project. Now that is probably not recognized east of the Rockies for a number of reasons. But there is little doubt, I think, in most people's minds that habitat is a key issue and the valuation of the habitat alteration on fish stocks is one of the key areas in Fisheries.

Evaluating the size of the project is very difficult. All of us know we can discuss and debate conclusions and results for a long time. One of the best ways for a person like myself is to make sure that the work is discussed openly and published. Therefore, workshops like this and subsequent publication of the results is, I think, a very important part of the Fisheries research. Therefore, I congratulate Gordon and congratulate all of you getting together and wish you all a successful workshop.

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INFORMAL COMMENTS ON THE CARNATION CREEK STUDY: WHY WE DID IT

It is good to see so many friends and associates from at least 10 years ago. There are people here that I haven't seen in that length of time. I have just returned from our Annual Meeting of the Washington/British Columbia Chapter of the American Fisheries Society in Vancouver. Our keynote speaker was Gerry Birch, a dedicated forester, an outspoken forester that many or most of you know. In the last few years, he has had considerable new insight into fisheries and logging matters.

Needless to say, there is no one in this room that has more interest in Carnation Creek that I do. I certainly expect that, in these next 3 days, we are all going to be vitally involved in the discussion about the results and, particularly, the application of those results to integrated resource management. Now let me set the scene just a bit.

In the late 1960s, the most popular environmental issue was logging and fish. What was happening to our fisheries and wildlife? The newspapers were full of articles. B.C. Hydro was far away in the Kootenays where Gordon Hartman and Jim Walker were fighting a valliant but losing battle to save part of the Columbia River. But here on the coast from northern California to southeast Alaska, the issue was logging; logging and fish. And here we are today, entering the 13th year since activity first started at Carnation Creek in 1970. Logging-fish conflicts are still headline-grabbing and emotional issues. Sure they have to share with acid rain, with Vancouver Island coal, and with mine tailings, but they still grab the public's attention. The fact that logging and fish remain so much public and technical issues, I think, emphasizes the role that the results of the long-term studies at Carnation Creek can play in improved watershed management. I believe the fact that we still have major unresolved conflicts justifies the original concept and goals to the Carnation Creek Project.

I was very frustrated, as were lots of others, with our apparent inability to technically solve, or at least moderate, the logging-fish concept. At that time, there was some work going on in northern California, in Oregon, and in Alaska. But we in British Columbia didn't seem to be getting very far.

With a fair amount of fervor and yet to be bloodied, Bruce Andersen and I went on from Babine Lake Sockeye Research and took on the big issues of the effects of logging in coastal British Columbia. Initial studies in 1969 (short-term studies in Nanaimo and Ash watersheds) revealed the logging impacts, lots of questions, and virtually no technical satisfaction. It became clear to me that what we needed was a long-term watershed study. This was crystallized by early discussions with Tom Bird and Forbes Boyd, who certainly had many ideas from Fisheries. Most of you know those two gents, who I think are here. They certainly had the same strong belief. Similar direction was provided by Jim Hall, who was completing, at that time, the Alsea River Study in Oregon. Jim is here and will be for the next 3 days. So, late in 1969, we started the search for the appropriate small watershed. We must have talked to every Fisheries officer on the coast, as well as with conservation officers, biologists, technicians, foresters, and logging people. We followed up lots of leads that turned out to be unsuitable. My biggest dragnet, not surprisingly, was MacMillan Bloedel. Continuing to this moment, we have had long-term support from Grant Ainscough.

Early in the spring of 1970, we located the Carnation Creek area as a possible study site. The rationale for selection of the study area really boiled down to four points. First, we felt that there were many old-growth coastal watersheds, or some watersheds, left. Second, the small streams and small tributaries of larger streams where the biological action is and where the problems are. Third, the current referral systems and general guidelines in British Columbia had limited success in reducing fisheries-forestry conflicts. The concern over, and problems with, the effects of logging activity on fish stocks were only symptoms of a lack of (this magic phrase) integrated resource management. Streams, wildlife, soils, and timber, we felt, were integral parts of the forest ecosystem and they couldn't be studied in isolation. They couldn't be managed in isolation. Unfortunately, previously that is exactly what we had been doing. And fourth, considering the rationales of the day for the study, in 1970 there was no information on research done in British Columbia on forestry-fisheries problems that could be used to improve coastal management guidelines. Resource managers of the day were, and even today are, forced to use information from Oregon, California, and Alaska in rationalizing protective clauses in tree-cutting plans. Most of these studies are difficult to apply to the shallow soil sites in many areas of British Columbia. That is a statement of the rationale of the day when we started the study, and I suspect it generally holds true today.

Finally, I must add some comments about the use of the experience gained from Carnation Creek. The Salmonid Enhancement Program (SEP) has provided us with an opportunity to develop quantifiable stream habitat population assessment techniques. Proven means of stream enhancement have evolved from SEP funding. And much of this comes from work on the Keogh River and other work in stream habitat improvement.

Many of you have seen the enhancement guide that those people from the Fish and Wildlife Branch and Fisheries and Oceans staff put together last year. With this increased knowledge of habitat and with a capability to improve strains, I think we have a potent management tool to be used perhaps in the time of logging or soon after, when the appropriate equipment is on site.

I believe that what we will review here over the next 3 days will point further to a number of physical stream improvement opportunities that may be used in streams like Carnation Creek and others. I believe that Dave Bustart's early work in Carnation Creek identified the major role played by backwaters in the overwinter survival of coho. It points to significant enhancement opportunity. We can build such backwaters and in fact, Jeff Cederholm, who is here from Washington's Department of Natural Resources, gave a paper yesterday at the American Fisheries Society Meeting on such backwaters in a natural situation. He identified improving parameters needed to build such backwaters artificially. In Washington, there is a program underway to do just that.

Another observation, that I could offer based on experience since I left Carnation Creek, has to do with the impact of over-fishing. It has been common for many of us through the years to blame the lack of fish on logging. There is no question that major stream damage has been done. We believe that most of our steelhead populations exist far below carrying capacity. That carrying capacity may be somewhat lower now than before logging, but nonetheless, our populations are well below the present carrying capacity. This applies to steelhead and, I believe, coho and chinook as well.

In closing, I would emphasize that the purpose of this workshop is to discuss what the Carnation Creek is all about. The workers want dialogue; they want feedback from you who have resource management responsibilities. The participants are not necessarily giving definitive papers. Many will be reporting on ongoing work; a few may be presenting finished work. It is going to be a tough 3 days and if you are here *only* to listen to scientific papers, neither researchers or managers may get full value. But if you are here today and are prepared to evaluate the results of this study in the context of your resource responsibilities or interests and are prepared to share ideas and discuss, you are in the right place.

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THE STUDY AREA:
AN INITIAL DESCRIPTION

At the outset of these proceedings, some readers may not be familiar with the Carnation Creek Study area. The following is a very brief description of the watershed, the climate, and the fish populations.

The Carnation Creek watershed is near Bamfield on Vancouver Island in a coastal hemlock and cedar forest zone. It is 10 km^2 in area. The major part of the drainage lies below the level of snowfall. Precipitation is somewhere in the neighborhood of 250 cm to 380 cm. The stream discharge ranges from about as low as 0.017 m^3/sec in the July-August period and a maximum of that is near 48 m^3/sec. Most of the discharge occurs in the winter time.

Stream temperatures in Carnation Creek range from winter lows of about 1°C to summer maxima around 18°C. Spawning populations of fish consist of 200 to 300 coho salmon, about 12 to 14 steelhead and cutthroat trout, and anywhere from 450 to 4200 chum salmon. Occasionally, there are small numbers of pink salmon spawning in the estuary. There are two species of sculpin in the stream. The fish populations are small, however, they are typical of many of the populations found in west coast streams.

There are no lakes in the main system, so we don't have that kind of influence affecting the watershed. The lower part of the system is a gravelly channel with a fairly modest gradient of about 20 m/km. Anadromous fish have access to about 3.5 km of the creek.

The study may be considered in three phases—a prelogging study, 1970 to 1975; a logging period, 1975 to about May 1981; and a postlogging monitoring phase which will last in the neighborhood of 4 to 5 years, 1981 to 1985.

During logging, three different kinds of forest harvest treatments have been applied in different areas of the drainage. In some reaches of stream, leave strips of variable width have been left. In some reaches, trees have been cut up to the streambank, but all have been felled away from the stream. There has been no logging activity in the channel. In one section of the stream, some trees were felled into the stream and, where necessary, were yarded from it. In this same section, some merchantable logs which were already in the stream were yarded out.

Further details of watershed description and logging programs will be provided in the papers, where specifically required.

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PREHARVEST VEGETATION AND SOILS OF CARNATION CREEK WATERSHED

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ABSTRACT

Vegetation and soil surveys of Carnation Creek watershed were conducted prior to forest harvesting. These surveys formed part of the baseline data on a coastal watershed of a multidisciplinary, interagency project to investigate the effects of forest harvesting on salmonid fish populations. Five plant associations and three subassociations are described and a map presented showing the distribution of these, mostly in complexes. The watershed occurs in a mature coastal western hemlock forest and the described associations are considered stable. The streamside vegetation, because of its potential in providing food, shade, and cover to fish populations, was mapped separately and in more detail. A graph indicating the percentage of the stream channel covered by vegetation at 10 m intervals is given. Deciduous trees and shrubs are considered the most important plant species in the food chain of fish. Landform, soils, and ecosite maps are presented to indicate the relationship of vegetation to the terrain. The vegetation is most closely associated to site moisture regimes, as inferred through aspect, slope, soil depth, and texture. Most materials are of volcanic origin, and soils are mostly coarse-textured. Shallow soils, bedrock outcrops, and steep slopes are common. These physical site components have implications to forest harvesting, site preparation, and reforestation.

INTRODUCTION

Carnation Creek, which empties into Numukamis Bay of Trevor Channel at Barkley Sound on the west coast of Vancouver Island (48°54'N, 125°01'W), has been the focal point of a multidisciplinary research team involved in elucidating the effects of forest harvesting on salmonid fish populations. The creek is about 6 km in length and drains a watershed of about 10 km^2 supporting an overmature western hemlock-amabilis fir-western red cedar forest on mostly colluvial materials. Elevation ranges from sea level at the mouth of the creek to about 670 m at the top of Mt. Blenheim, although most of the watershed lies below 450 m.

Most of the research conducted in the watershed is focused on the streambed per se and the aquatic life associated with it. Hydrological considerations must include the upland areas, as well as the actual stream channels. Precipitation falling on the uplands gives rise to fluctuations in stream water levels and discharge velocities. As precipitation moves from point of contact on the upland surface to the stream channel, it may carry with it plant and soil materials during overland flow or soil nutrients by infiltration and subsequent groundwater flow. Any materials brought into the stream affects its chemistry and influences its potential for supporting living organisms. Therefore, it is important to know the vegetation of the watershed because it provides the material available for transport to the stream either as raw material, as breakdown products through decomposition or nonaquatic animal life (insects, microorganisms, soil fauna, birds, mammals, etc., and their waste products) that may be associated with the vegetative debris. Also, the vegetation serves to protect the soil from erosion. The soil is important because it largely governs the type of precipitation discharge (overland or percolation) and has a strong influence on the amount and kinds of materials brought into the stream through groundwater flow. The topography, along with the soil, in a given environmental setting, influences the type of vegetation growth, including species distribution, and is relevant to the potential erosion subsequent to disturbance.

This report brings together the information gathered during three prelogging surveys of the vegetation and soils and presented as preliminary reports (Oswald 1973, 1974, 1975). The surveys of the upland areas were conducted using panchromatic aerial photographs at a scale of 1:15 840 and field examination; the stream channel was surveyed by walking up the streambed and recording the vegetation and percent cover by trees and shrubs over the channel at 10 m intervals. The scale of mapping has been reduced to 1:25 000 for the watershed as a whole, but the more detailed map of the lower channel and adjacent banks has been retained. Landform and soil maps, prepared by the Resource Analysis Branch, Ministry of the Environment, have been enlarged to 1:25 000 and included.

The author wishes to acknowledge the services of Mr. Barry Brown who was involved with the initial field work and drafted all the maps.

VEGETATION

Carnation Creek lies within the Coast Forest Region of Rowe (1972), the Coastal Western Hemlock Biogeoclimatic Zone of Krajina (1969), and the West Vancouver Island Submontane Variant of the Wetter Maritime Coastal Western Hemlock Subzone of Klinka (1977). It is equatable for the most part to the *Tsuga heterophylla* Zone of Franklin and Dyrness (1969), except that they also recognize a *Picea sitchensis* Zone which would include part of the watershed similar to the Fog Western Hemlock-Sitka Spruce Subzone of Packee (1974).

The trees throughout the watershed consisted primarily of overmature *Tsuga heterophylla* (see Appendix for list of common names of plant species) and *Abies amabilis* with a lesser amount of *Thuja plicata* and a scattering of other species. The largest, and possibly the oldest, trees were *Thuja plicata*, but age determinations were hampered by decay in the lower bole heartwood. *Pseudotsuga menziesii* occurred on the drier sites, most of which were on bedrock-controlled ridge tops and shallow soils over talus material on upper slope positions. *Picea sitchensis* was sparsely distributed on moist to wet, well-drained sites, mostly near the creekbed. *Pinus monticola* was limited to the upper slopes of Mt. Blenheim, where it was represented by only a few trees. *Alnus rubra* and *Acer macrophyllum* constituted a significant proportion of the tree cover along the creek floodplain.

Five plant associations and three subassociations were recognized from the analysis of understory vegetation, in respect to tree cover on upland sites. These types, in essence, represent a gradient in site moisture regimes developed by variations in internal site temperatures and drainages caused by topographic and edaphic differences. The associations and subassociations are named following the Zurich-Montpellier School of Phytosociology advocated in British Columbia by Krajina (1969). Table 1 indicates the relationship of the plant communities, preceded by the hierarchical scheme and suffixes of the Zurich-Montpellier system. Common or anglicized names of the communities recognized in the study are given and are numbered for easier reference. Authorities are given for those communities described by others.

1. Douglas-fir/Salal association

The Douglas-fir/Salal association occurred on well- to excessively-drained colluvial slopes that had a southern or western aspect or on tops of ridges or knolls that had shallow soils over bedrock. *Gaultheria shallon* tended to occur mostly in openings of the tree canopy. Other shrubs commonly occurring in the association included *Menziesia ferruginea*, *Rubus spectabilis*, *Vaccinum ovalifolium*, *V. ovatum*, and *V. parvifolium*, although the density, height, and growth form (vigor) of these species were variable from one area to another. A likely variant of this association is indicated by *Vaccinium ovatum* which was present on rocky knolls with exposed bedrock and coarse colluvium, but this only occurred to a minor extent in the western part of the watershed. *Athyrium filix-femina*, *Blechnum spicant*, *Tiarella laciniata*, and *T. trifoliata* were the most common forbs in the association but were sparsely distributed and primarily occurred under shrubs and trees. Mosses were mostly confined to logs and stumps, but occasionally occurred on litter, and consisted of *Eurhynchium oreganum*, *Hylocomium splendens*, *Rhizomnium glabrescens*,

Table 1. Vegetation classification hierarchy.

Level	Suffix
Order	--etalia
Alliance	--ion
Association	--etum
Subassociation	--etosum
Common name	

I. Pseudotsugetalia menziesii (Krajina 1969)

- A. Gaultherion shallonis
  - a. Hylocomio (splendentis)-Eurhynchio (oregani)-Gaultherio (shallonis)-Pseudotsugetum menziesii
  - 1. Douglas-fir/Salal association

II. Tsugetalia heterophyllae (Krajina 1969)

- B. Hylocomio (splendentis)-Gaultherio (shallonis)-Tsugion heterophyllae
  - b. Hylocomio (splendentis-Vaccinium (alaskaensis)-Gaultherio (shallonis)-Tsugetum heterophyllae
    - (a) Gaultheretosum shallonis
    - 2. Western hemlock/Salal subassociation

  - c. Hylocomio (splendentis)-Eurhynchio (oregani)-Blechnio (spicantis)-Gaultherio (shallonis)-Tsugetum heterophyllae
  - 3. Western hemlock/Salal-Deer fern association

- C. Eurhynchio (oregani)-Blechnio (spicantis)-Polysticho (muniti)-Abieto (amabilis)-Tsugion heterophyllae
  - d. Eurhynchio (oregani)-Blechnio (spicantis)-Abieto (amabilis)-Tsugetum heterophyllae
    - (b) Blechnetosum spicantis
    - 4. Western hemlock-Amabilis fir/Deer fern subassociation

    - (c) Polystichetosum munitis
    - 5. Western hemlock-Amabilis fir/Sword fern-Deer fern subassociation

  - e. Eurhynchio (oregani)-Polysticho (muniti)-Abieto (amabilis)-Tsugetum heterophyllae
  - 6. Western hemlock-Amabilis fir/Sword fern association

Plagiothecium undulatum, and *Rhytidiadelphus loreus*. Associated tree species were *Tsuga heterophylla* on drier sites and *T. heterophylla*, *Abies amabilis*, and *Thuja plicata* on more moist sites. This association had the lowest forest capability relative to other associations in the watershed, largely due to the amount of exposed bedrock and shallow, excessively-drained soils.

2. Western hemlock/Salal subassociation

This community was prevalent on ridge tops and on shallow colluvial soils that were rapidly drained. It is presumably equivalent to the legosolicum Vaccinium alaskaensis-Gaultheria subassociation of the Tsugeto-Gaultherietum association of Orloci (1961) which is a dry edaphic zonal forest type of the wet and cool coastal western hemlock subzone.

The moss layer was usually well developed. *Hylocomium splendens* often formed a nearly continuous mat over the ground and litter. *Rhytidiadelphus loreus*, *Scapania* sp., and *Dicranum* spp. were common on logs and stumps. *Isothecium spiculiferum* was the most abundant epiphyte, but liverworts and other mosses were also present on tree trunks and branches. *Gaultheria shallon* was the most common shrub but had low vigor, although the height was often over 2 m. *Vaccinium parvifolium* and *V. alaskaensis* were always sparsely present and *V. ovatum* was rarely present. *Listera cordata* was present throughout most of the association, occurring as scattered individuals. *Blechnum spicant* was present only in more moist situations. *Tsuga heterophylla* was the most prevalent tree species, but *Abies amabilis* and *Thuja plicata* were usually present. Except for *T. plicata*, most larger trees had broken tops. The forest productivity is only slightly better than the Douglas-fir/Salal association.

3. Western hemlock/Salal-Deer fern association

This association is characterized by a moderate to thick layer of *Gaultheria shallon* and an undergrowth of *Blechnum spicant*. *G. shallon* had its best growth in, and was sometimes restricted to, openings in the tree canopy, where it attained heights of about 2 m. *B. spicant* occurred under the shrubs and trees, indicating its requirement for more moist conditions provided by the shade. This community is possibly transitional between Western hemlock/Salal and Western hemlock-Amabilis fir/Deer fern.

Bryophytes and forbs, other than *Blechnum spicant*, were generally sparse and included *Eurhynchium oreganum*, *Hylocomium splendens*, *Plagiothecium undulatum*, *Rhytidiadelphus loreus*, *Athyrium filix-femina*, and *Polystichum munitum*. *P. munitum* was usually confined to the more moist situations, such as depressions or denser cover. Shrubs were plentiful and consisted of *Menziesia ferruginea*, *Rubus spectabilis*, *Vaccinium ovalifolium*, *V. ovatum*, and *V. parvifolium*; occasionally, one of these would form a codominant with *Gaultheria shallon*. *Tsuga heterophylla* was the most common tree species, but variable amounts of *Abies amabilis*, *Pseudotsuga menziesii*, and *Thuja plicata* were present. Regeneration mostly consisted of *T. heterophylla* and *A. amabilis*, although some *P. menziesii* saplings occurred in larger openings of the canopy. The productivity is estimated to be virtually the same as the Western hemlock/Salal association.

4. Western hemlock-Amabilis fir/ Deer fern subassociation

The Western hemlock-Amabilis fir/Deer fern subassociation is the most prevalent community in the watershed and generally indicates mesic or modal conditions. Its best development is on north-facing slopes, although it occurs on other aspects as well, where the soil depth is about 30 cm or more. It is related to the Abieteto-Tsugetum heterophyllae association of Orloci (1961) in which he has two variants—the clintoniosum and the acerosum circinati—but these have only sparse inclusions of deer fern. Kojima and Krajina (1975) recognize a Rhytidiadelpho (lorei)-Plagiothecio (undulati)-Rubo (pedati)-Vaccinio (alaskaensis)-Abieto (amabilis)-Tsugetum heterophyllae association where deer fern is sometimes present. Because of the lush growth of deer fern, usually providing more than 50% cover, and the absence of any other consistent diagnostic species, it would seem realistic to recognize it at least at the subassociation level.

The bryophyte layer was poorly developed with *Eurhynchium oreganum* being the most consistently present species. *Hylocomium splendens, Rhizomnium glabrescens, Plagiothecium undulatum, Rhytidiadelphus loreus,* and *Sphagnum girgensohnii* were sometimes present. *Isothecium spiculiferum* was a common epiphyte occurring from base to near top of crown on most trees. Forbs were very sparse, except for *Blechnum spicant*, and included *Polystichum munitum, Streptopus amplexicaulis, Tiarella laciniata, T. trifoliata,* and *Trillium ovatum*. Shrubs were only slightly more prevalent, with *Rubus spectabilis, Vaccinium ovalifolium,* and *V. parvifolium* having the highest degree of constancy and *Gaultheria shallon* and *Menziesia ferruginea* occurring mostly on logs and stumps. The growth form of the shrubs revealed low vigor, although heights of 1.5 m or more were not uncommon. *Tsuga heterophylla* usually provided the highest percent canopy cover, although *Abies amabilis* was always present but sometimes sparse. *Thuja plicata* was often present, but never abundant, and frequently were the largest trees in diameter. *Pseudotsuga menziesii* was occasionally present on drier situations, and *Pinus monticola* occurred at higher elevations (about 600 m) on Mt. Blenheim. *Picea sitchensis* was present near the creek. *Tsuga heterophylla* and *Abies amabilis* produced the most regeneration, but some *Thuja plicata* saplings were sometimes present. The productivity was generally better than in the previous communities.

5. Western hemlock-Amabilis fir/ Sword fern-Deer fern subassociation

This subassociation appears to be transitional between the Western hemlock-Amabilis fir/ Deer fern and the Western hemlock-Amabilis fir/Sword fern associations. This same assemblage of plants has been observed at other points in the coastal forest and is always in mature conditions with no evidence of instability. Therefore, it is here recognized as a stable edaphic subassociation. It occurs on soils that receive seepage and consequently never dry out. The relative amounts of *Blechnum spicant* and *Polystichum munitum* appear to reflect the moisture conditions as *B. spicant* is most abundant in the less moist and *P. munitum* in the more moist situations.

The bryophyte layer was poorly developed, mostly being confined to logs and stumps. *Eurhynchium oreganum, Hylocomium splendens, Plagiothecium undulatum, Plagiomnium insigne, Rhizomnium glabrescens, Rhytidiadelphus loreus, Sphagnum girgensohnii,* and various liverworts were usually present. *Isothecium spiculiferum* was an abundant epiphyte forming lush growth on trunks and most branches of nearly all trees. Forbs, other than *Blechnum spicant* and *Polystichum munitum*, were virtually nonexistent, but occasionally, *Athyrium filix-femina, Claytonia sibirica, Moneses uniflora, Tiarella trifoliata,* and *Trillium ovatum* were present. Shrubs were also sparse, of low vigor, and rooted mostly in logs and stumps. *Rubus spectabilis, Vaccinium ovalifolium, V. alaskaensis,* and *V. parvifolium* were the most common. *Tsuga heterophylla* was usually the dominant tree species, but in some places, *Abies amabilis* was more prevalent. *Thuja plicata* was usually present and formed the largest trees, but its frequency relative to other tree species was low. *Pseudotsuga menziesii* was sometimes present at higher elevations on drier sites, and *Picea sitchensis* occurred near the creek. *Alnus rubra* was sometimes present, but evidence based on snags, stumps, and logs indicated it was being eliminated in most places. This association was indicative of very good site potential for tree growth, especially where *Polystichum munitum* was most abundant.

6. Western hemlock-Amabilis fir/ Sword fern association

This association occurred on the wettest sites that had well-drained soils. Although moisture was rarely or never lacking, the drainage was such that stagnation, if present, was minimal and gleization was seldom encountered in the soils. Consequently, the association is indicative of the best potential for tree growth in the watershed.

The bryophyte layer was thin and discontinuous, but generally better developed than most other associations in the deer fern and sword fern alliance. *Eurhynchium oreganum, Plagiothecium undulatum,* and *Rhizomnium glabrescens* were usually the most prevalent species, but mostly occurred on logs and stumps. *Isothecium spiculiferum* was present on logs and stumps, as well as being an abundant epiphyte on trees. *Leucolepis menziesii* and *Sphagnum squarrosum* occurred in the wettest areas such as depressions that retained water for portions of the year or had deep organic layers. *Polystichum munitum* was by far the most dominant forb, as it formed lush growth that provided up to 80% ground cover. Other associated forbs included *Adiantum pedatum*, *Athyrium filix-femina*, *Blechnum spicant*, *Gymnocarpum dryopetris*, *Galium triflorum*, *Maianthemum dilatatum*, *Claytonia sibirica*, *Tiarella laciniata*, *T. trifoliata*, *Trillium ovatum*, and *Veratrum viride*, but none were consistently present and they were never abundant. Similarly, shrubs such as *Menziesia ferruginea*, *Rubus spectabilis*, and *Vaccinium* spp. provided little coverage for the most part but occurred in localized patches. *Tsuga heterophylla* was usually the most common tree species, but occasionally, dominance was shared or assumed by *Abies amabilis*. *Thuja plicata* was always present and formed the largest trees but provided relatively little coverage. *Picea sitchensis* was a common associate of the community and *Pseudotsuga menziesii* was sometimes present. *Alnus rubra* was more prevalent in this association than any other.

This subassociation appears similar to the polystichosum muniti variant of the Eurynchio-Tiarello-Polysticho-Achlydo-Pseudotsugo-Tsugo-Thujetum association of Kojima and Krajina (1975) which they include in the Mohonia (nervosae)-Polystichion muniti alliance of the Thujetalia plicatae order; and to the hylocomietosum splendentis subassociation of the Thujeto-Polystichetum Association of Orloci (1961). Although *Thuja plicata* was nearly always present and usually constituted the largest trees, it seems more appropriate to place the Carnation Creek communities in the Tsugetalia heterophyllae, since *Tsuga heterophylla* provided the greatest amount of cover and both *T. heterophylla* and *Abies amabilis* regeneration was more evident than *Thuja plicata*. The difference may lie in that Kojima and Krajina (1975) and Orloci (1961) did their analyses on vegetation of the coastal mainland at a higher elevation. They indicate other associated species than those of the west coast of Vancouver Island, and some species occupy different habitats, e.g., Orloci (1964) reports *Blechnum spicant* occurring on wet sites and *Polystichum munitum* on somewhat drier sites—the opposite of what was found in this study.

The described associations and subassociations were distributed on the landscape in such an intricate manner that it was virtually impossible to map them separately at a scale of 1:25 000. A map of the vegetation was constructed, indicating the more prevalent assemblages of vegetation types (Fig. 2). The legend was constructed with the driest communities at the top and progresses, in general, to more moist communities, although there was little difference in the last three. Forest capability follows a similar pattern, with the driest sites having the lowest capability and the more moist sites the best; however, due to decadence of the existing stands, actual capability figures could not be determined. Tree growth did not appear limited by too much water, except in some old meander scars along the creek; forested swamps did occur in upland basins just outside the watershed boundaries.

It was considered that the vegetation immediately adjacent to the stream channel could have a considerable influence on fish populations by providing an important food link through litter fall and attracting insects and birds, in addition to providing shade and cover. Therefore, this vegetation was examined in greater detail than for the rest of the watershed. The stream channel consisted of a gently sloping lower reach of about 3100 m, a steeply sloping middle reach of about 1000 m with falls near the lower end impassable to anadromous fish, and a gently sloping upper reach. Since the primary interest of the overall project was in relation to anadromous fish, only the vegetation along the lower reach was mapped (Fig. 1). The middle reach had steep rocky banks forming a canyon and supported the Western hemlock/Salal-Deer fern association for the most part. The upper reach was similar to the lower one, with *Alnus rubra* and *Rubus spectabilis* being common.

The tree cover of the lower reach consisted primarily of *Tsuga heterophylla*, *Thuja plicata*, *Alnus rubra*, *Abies amabilis*, and *Picea sitchensis*. *A. rubra* was believed to be more important than the other species in providing food through leaf drop and associated insect remains and, therefore, most occurrences of this species are indicated on the map. There was little correlation between tree species occurrence and site conditions. *Alnus rubra* appeared to require an opening to get established but would then persist well into stand maturity, especially on wetter sites.

The undergrowth, on the other hand, appeared to be governed by site conditions. *Gaultheria shallon* occurred on somewhat elevated areas such as rocky knolls, stumps, and logs. *Rubus spectabilis, Ribes bracteosum, Sambucus racemosa,* and *Menziesia ferruginea* occurred in openings on more moist sites, and *Vaccinium* spp. and *Polystichum munitum* occurred under the tree canopy on these sites. *Tiarella trifoliata, T. laciniata, Maianthemum dilatatum, Trillium ovatum,* and *Gymnocarpum dryopteris* were common forbs, being more prevalent on moist, than on dry, sites. In the wettest sites, such as bogs, fens, and swamps formed by back-water channels and old meander scars, *Lysichitum americanum, Veratrum viride, Adenocaulon bicolor, Adiantum pedatum, Scirpus* spp., *Carex* spp., and *Sphagnum* spp. were common associates. *Oplopanax horridum* occurred in only one location in the lower reach, but was more plentiful in the upper reach.

The percentage of cover over the stream channel provided by the vegetation is indicated at 10 m intervals along the lower reach in Fig. 3. In addition to *Alnus rubra* being an important link in the food chain for fish, many of the shrubs are perhaps equally important in attracting insects, birds, and microorganisms. *Rubus spectabilis* is considered the most important shrub in this regard because of its prolific flower and fruit production. In addition to the shade and potential food supply, vegetative debris can accumulate in the stream channel which, when large enough, can cause the formation of pools or alter the channel through diversion of the streamflow. Trees are perhaps the most important because of their size and the probability of them becoming firmly lodged. Smaller debris can become tangled in a lodged tree which compounds the jamming effects. Logjams have been caused by strong winds blowing several trees over which become tangled at some point in the stream.

SOILS AND PARENT MATERIALS

The soils in the watershed have developed largely from the decomposition of local rock that has moved a short distance through glaciation and subsequent colluvial action. Most of the bedrock is Jurassic volcanics of the Bonanza Group consisting of basaltic to rhyolitic lava, tuff, breccia, minor argillite, and greywacke, but the higher areas to the south and east are Island Instrusives consisting of granodiorite, quartzdiorite, granite, and quartz monzonite (Muller 1977). The area was glaciated during the Wisconsin glaciation and scouring and subsequent outwash apparently removed any marine material that may have been deposited during the period when the land mass was depressed relative to the ocean. Also, no compacted glacial till was found in the watershed, although it occurred in adjacent valleys. The surficial materials were mapped by Alley and Jungens (Fig. 4) as a mixture of morainal (till) and colluvial materials. Most rock fragments in the soil are angular, indicating they were not moved far from their origin.

The soils were mostly coarse-textured, well-drained, and were classed as Orthic Ferro-humic Podzols (Canada Soil Survey Committee 1978), except in fluvial areas (Fig. 5). Regosols occurred on the steep rocky areas and in the more active alluvial channels. Shallow soils and bedrock outcrops were common. Organic soils were uncommon, but occurred in relict depressions on upland areas and in old channel scars along the stream floodplain. Most soils were strongly to very strongly acid (pH 3.0 to 5.5 in $CaC1_2$) and the pH was generally lowest in the upper horizons (Oswald 1973, 1974). Conductivities were about 300 umho (237 to 488 umho) in the upper mineral horizon and dropped about threefold (74 to 198 umho) in the C horizon; this gives an indication of soluble salt concentrations which would be expected to be low in acid soils. Most soils had moderately thick humus layers (15 cm to 40 cm) and in some places the entire plant substrate consisted of organic matter up to about 60 cm in depth on bedrock or coarse rock fragments. There appeared to be good infiltration of organic material into the soil, as most often the percent carbon in the B horizon was relatively high and there was sometimes a pronounced increase in carbon in the upper part of the C horizon (Oswald 1973), forming an ortstein horizon.

The terrain was also divided into Ecosites (Fig. 6) to reveal more of the edaphic situations by combining soil depth, slope, and aspect conditions. These units should have more relevance to harvesting operations, site preparation, reforestation, and tree growth than the soils or landform maps because they reflect the interrelationship of aspect and soils, as revealed by the mature vegetation. Most logging operations, including haul-road construction, are more easily conducted on level to gently sloping ground with a reasonable amount of unconsolidated material. Also, deeper soils are more resilient to the type of disturbance caused by logging operations; however, the possibility of mass wasting may be greater. The potential for subsequent erosion will be greatest on steeper slopes, especially where there is little mineral soil. Slash removal by prescribed burning is more difficult to achieve on north aspects than on south aspects, and fires will burn hotter due to drier conditions on south aspects, resulting in the removal of more organic matter and, thereby, soil nutrients. The success of reforestation by planting will be better on north aspects that have a reasonable amount of soil material, and species selections will probably require alterations on different site conditions.

It can be seen that a significant proportion of the watershed consists of moderately to steeply sloping terrain often with shallow soils. These will require a reasonable amount of care during the forest harvesting and subsequent preparation for reforestation phases to prevent undue site deterioration through erosion and nutrient loss. The steep, rocky south aspects will be difficult to reforest unless there are optimal weather conditions during the establishment phases. It can be anticipated that shrubs, primarily *Rubus spectabilis*, will quickly invade the more gentle, moist slopes and will retard early tree growth. Also, some increase in *Alnus rubra* can be expected on alluvial sites and adjacent colluvial soils, initially through propagation by vegetative means and later from seed. *Pseudotsuga menziesii* would probably be the preferred species for planting on shallow soils and steeper south aspects, while *Tsuga heterophylla* and *Abies amabilis* may be preferable on more moist sites. *Thuja plicata* would do well on the wetter sites and *Picea sitchensis* on alluvium.

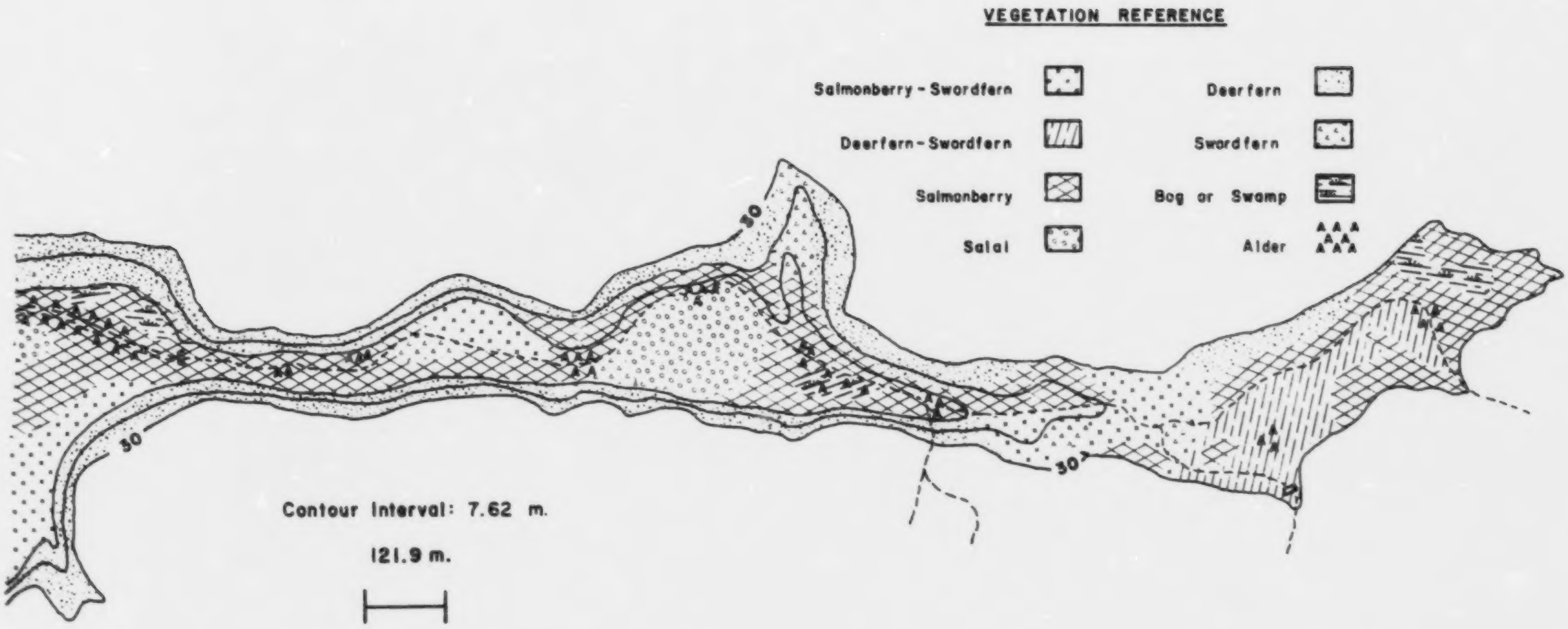

VEGETATION REFERENCE
Salmonberry - Swordfern
Deerfern - Swordfern
Salmonberry
Salal
Deerfern
Swordfern
Bog or Swamp
Alder
30
30
30
Contour Interval: 7.62 m.
121.9 m.

Fig. 1. Streamside vegetation of the lower reach of Carnation Creek.

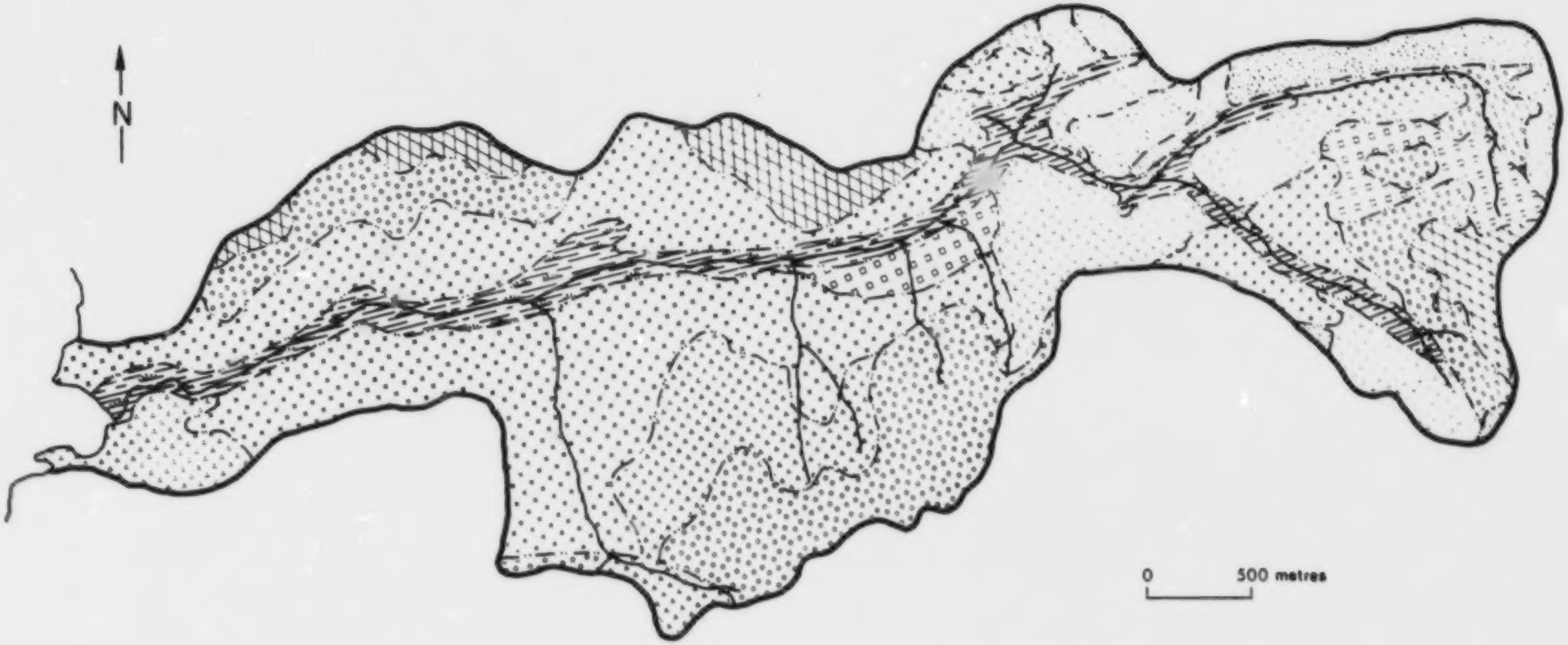

N
0
500 metres

Fig. 2. Vegetation of Carnation Creek.

LEGEND FOR VEGETATION MAP

▨	Douglas-fir/Salal association on shallow, rocky soils and in interstices of exposed bedrock.
░	Primarily Western hemlock/Salal association with inclusions of Douglas-fir/Salal on ridge tops and upper southerly and western exposures on shallow soils.
⁙	Western hemlock/Salal and Douglas-fir/Salal associations on upper slopes and tops of hills with inclusions of Western hemlock/Salal-Deer fern and Western hemlock-Amabilis fir/Deer fern. Usually has some Western red cedar.
∴	Western hemlock/Salal-Deer fern subassociation primarily with inclusions of Douglas-fir/Salal and Western hemlock-Amabilis fir/Deer fern. Some Sitka spruce and Western red cedar are often present.
⁚	Primarily Western hemlock-Amabilis fir/Deer fern with inclusions of Western hemlock/Salal-Deer fern, Western hemlock-Amabilis fir/Sword fern-Deer fern and Western hemlock-Amabilis fir/Sword fern. Douglas-fir is present on drier sites, Sitka spruce near the stream channel and Western red cedar sparsely throughout.
☰	Creek channel communities with variable mixtures of Western hemlock, Amabilis fir, Western red cedar, Sitka spruce, Douglas-fir, Red alder and Broadleaf maple in overstory and Salmonberry, Sword fern, Deer fern and Salal in the understory. Devils club occurred in a few patches.
⊞	Nearly pure Western hemlock-Amabilis fir/Sword fern - Deer fern in moisture receiving areas.

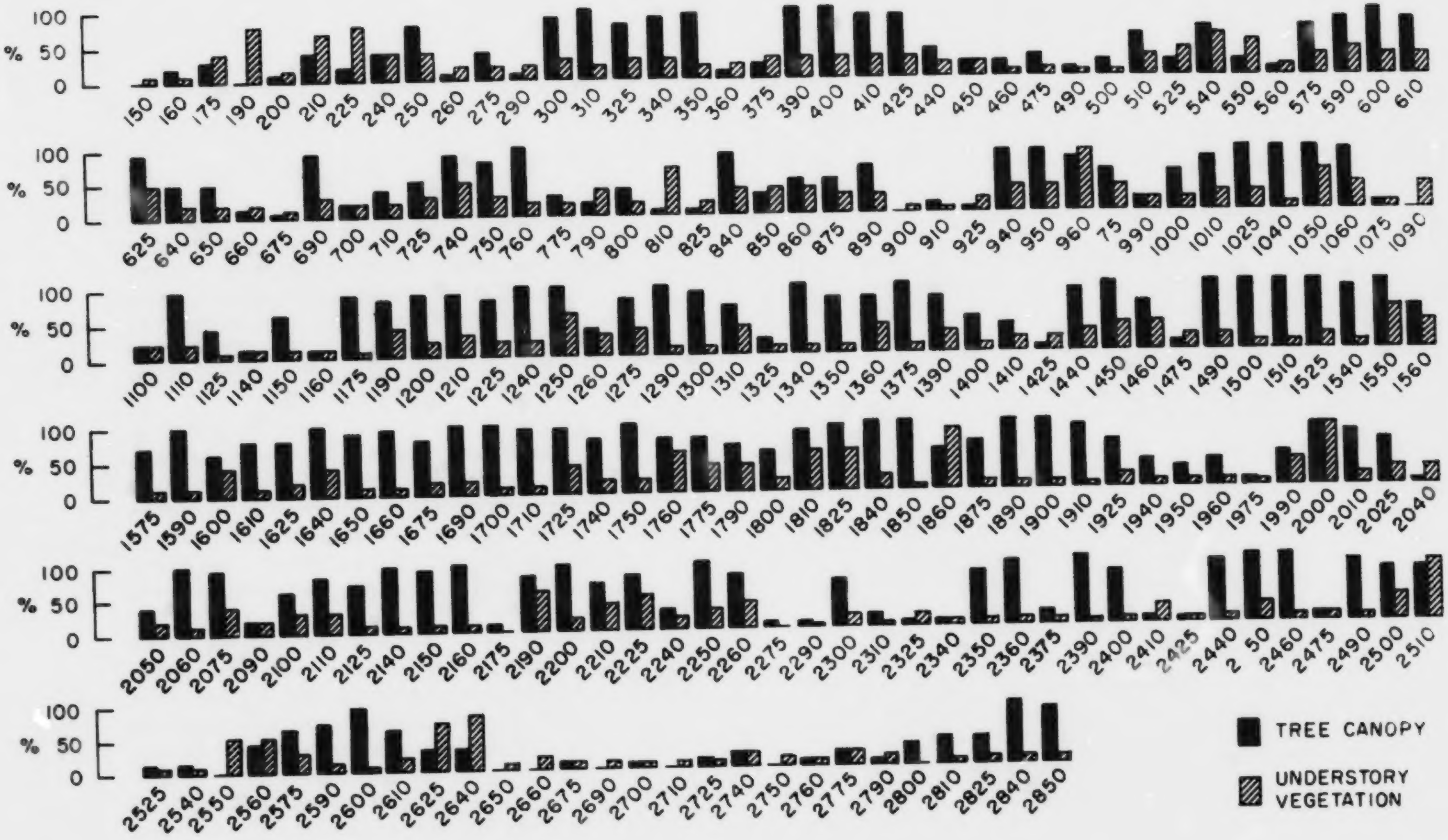
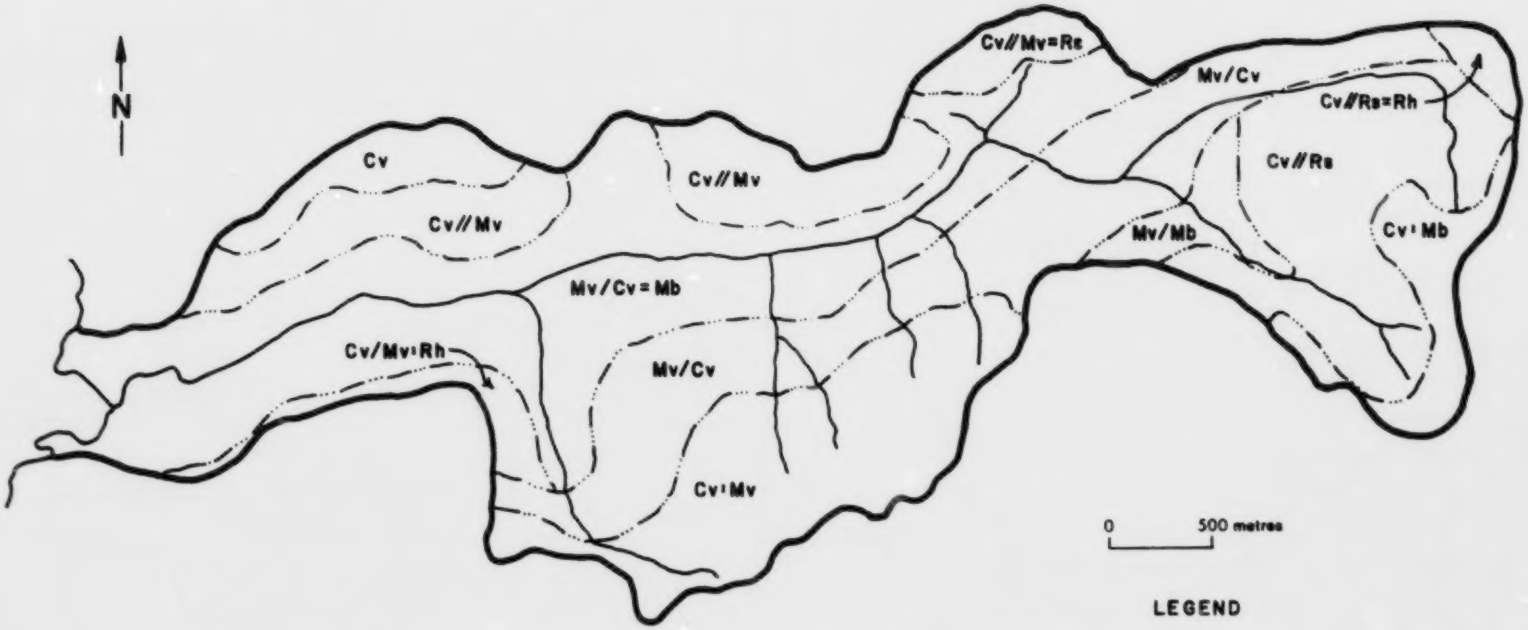


Fig. 3. Percentage of closure over the stream channel along the lower reach of Carnation Creek at designated points.


N
Cv
Cv//Mv
Cv//Mv
Cv//Mv=Rs
Mv/Cv
Cv//Rs=Rh
Cv//Rs
Cv:Mb
Mv/Mb
Mv/Cv=Mb
Cv/Mv:Rh
Mv/Cv
Cv:Mv
0
500 metres

LEGEND

Cv	Colluvial Veneer
Mv	Morainal Veneer
Mb	Morainal Blanket
Rh	Rock Hummocks
Rs	Steep Rock

= Components equal (50% = 50%)

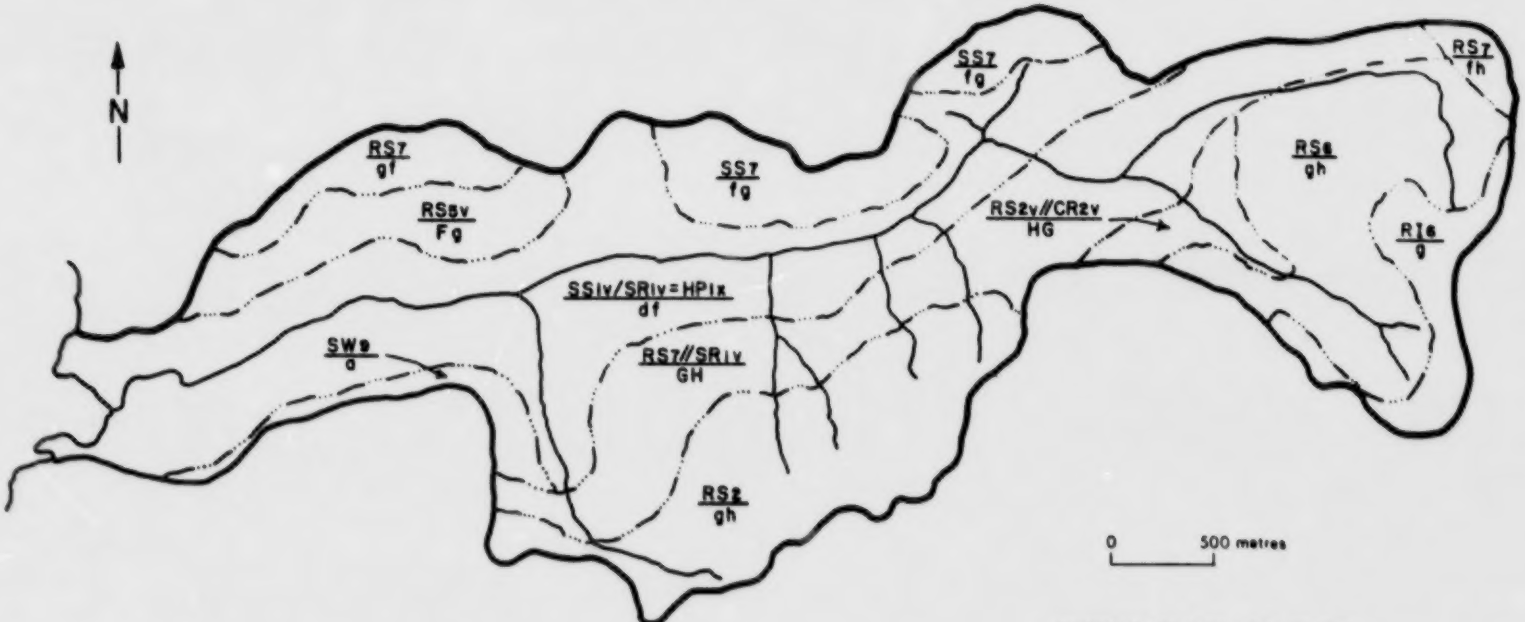
/ Component in front more abundant (60% / 40%)

// Component in front considerably more abundant (80% // 20%)

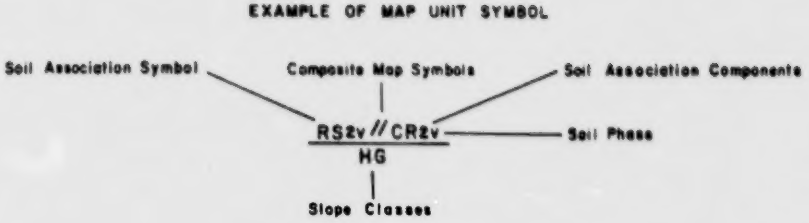
: Component in front is very much more abundant (90% : 10%)

Map and Legend adapted from 1:50,000 maps compiled by N. Alley (Sheet 92C/15) and J. Jungens (Sheet 92C/14) for Resource Analysis Branch, Ministry of Environment, Victoria, B.C.

Fig. 4. Landforms of Carnation Creek.


N
RS7
gf
RS5v
Fg
SS7
fg
SS7
fg
RS7
fh
RS6
gh
RI6
g
RS2v//CR2v
HG
SSIv/SRIv=HPIx
df
SW9
a
RS7//SRIv
GH
RS2
gh
0
500 metres

EXAMPLE OF MAP UNIT SYMBOL


Soil Association Symbol
Composite Map Symbols
Soil Association Components
RS2v // CR2v
HG
Soil Phase
Slope Classes

Map and Legend adapted from 1:50,000 maps (Sheets 92C/14 & 92C /15) compiled by J. Jungens for Resource Analysis Branch, Ministry of Environment, Victoria, B.C.

Fig. 5. Soils of Carnation Creek.

SOILS MAP LEGEND

SOIL ASSOCIATION DESCRIPTONS

SYMBOL	NAME	PARENT MATERIAL	MOST COMMON TEXTURE	MOST COMMON DRAINAGE	MOST COMMON SOIL
RS	Reeses	colluvium	gsl	well	O.FHP - shli
SS	Sprise	colluvium	gls	well	O.FHP - shli
RI	Rainier	colluvium	gsl	well	O.FHP - shli
CR	Cotter	colluvium	gls	well	O.FHP
SR	Sarita	moraine	gsl	mod. well	Du. FHP
SW	Sugsaw	fluvial	ls/gls	poor	R.HG
HP	Hooper	fluvial	vgls	mod. well	OT. FHP

COMPOSITE MAP SYMBOLS

SYMBOL	DESCRIPTION
=	Components approximately equal (50 % = 50 %)
/	Component in front is more abundant (60 % / 40 %)
//	Component in front is considerably more abundant (80 % // 20 %)

SOIL ASSOCIATION COMPONENTS

SYMBOL	DESCRIPTION
1	This is the modal or most commonly occuring soil within this association, as described above and is the only significant soil found in areas mapped by component 1. Components 2 and 5 contain the modal soil and a second less common soil. Components 6, 7 and 9 are exceptions as they contain only a minor portion of the modal soil.
2	Less common soil is drier than modal soil due to texture, aspect, etc.
5	Less common soil is shallower to bedrock than modal soil.
6	Shallower soils are most common, modal soil being less common.
7	Modal soil has a different soil profile development within the same environment (such as presence of duric horizons). Variable component.
9	Modal soil is saline.

SLOPE CLASSES

SYMBOL	DESCRIPTION
gf	Multiple slopes, 30 to 60 % dominant, significant inclusions of 15 to 30 %
fg	Multiple slopes, 15 to 30 % " , " " of 30 to 60 %
fh	Multiple slopes, 15 to 30 % " , " " of >60 %
gh	Multiple slopes, 30 to 60 % " , " " of >60 %
df	Multiple slopes, 5 to 9 % " , " " of 15 to 30 %
g	Multiple slopes of 30 to 60 %
a	Multiple slopes, nearly level, 0 to 0.5 %
GH	Single slopes, 30 to 60 % dominant, significant inclusions of >60 %
HG	Single slopes, 60 % dominant, significant inclusions of 30 to 60 %
Fg	Dominately 15 to 30 % single slopes, significant inclusions of 30 to 60 % multiple slopes

SOIL PHASES

v - 20 to 50 % of the soil association component is affected by seepage.

x - 20 to 50 % of the soil association component is affected by imperfect drainage resulting in gleyed soils.

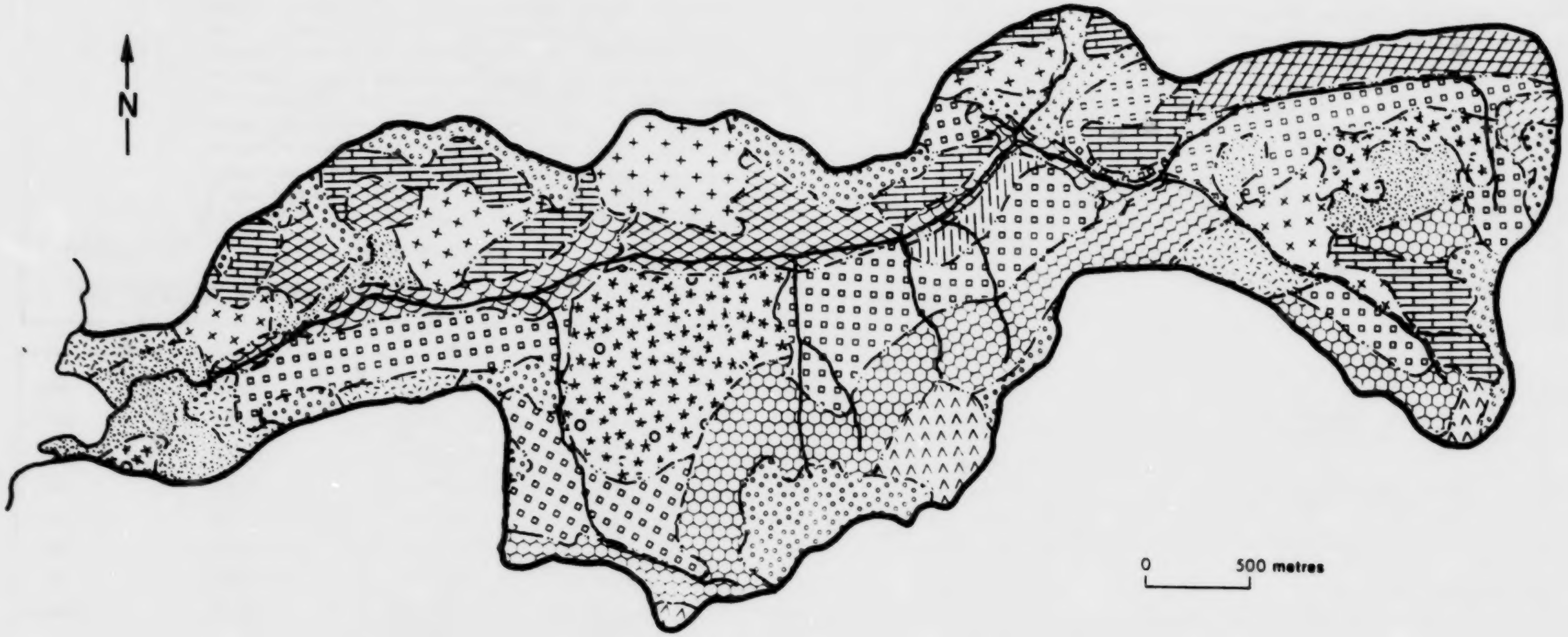

N
0
500 metres

Fig. 6. Ecosites of Carnation Creek.

LEGEND FOR ECOSITE MAP

░	Ridge tops with exposed bedrock, shallow soils over bedrock and steeply sloping southerly aspects.
▒	Steep to very steep northerly aspects below crests.
▤	Moderate to steeply sloping southerly aspects with shallow colluvial soils.
▩	Moderately sloping southerly aspects with moderately deep soils and convex surfaces.
⊡	Moderately to gently sloping southerly aspects, generally concave, moderately deep soils.
░	Gently sloping receiving areas, mostly convex southerly and westerly aspects, soils moderately deep.
░	Gently sloping westerly aspects, concave or convex, receives some drainage water, soils moderately deep.
⁙	Moderate to steeply sloping northerly aspects, soils shallow to moderately deep.
✲	Gently to moderately sloping northerly aspects, convex, moderately deep soils, receiving sites mostly below steeper slopes.
^	High elevation northerly aspects or ridge tops, steeply to moderately sloping, shallow soils on colluvium.
⁘	Moderately steep receiving sites adjacent to drainage channels, with mixed alluvium and colluvium.
▥	Gently sloping northerly aspects with alluvial capping over colluvium, receiving sites adjacent to drainage channels.
▩	Creek channel recent alluvial regosols.

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APPENDIX

LIST OF PLANT NAMES

Trees

Abies amabilis (Dougl.) Forbes	Amabilis fir
Acer macrophyllum Pursh	Broadleaf maple
Alnus rubra Bong.	Red alder
Picea sitchensis (Bong.) Carr.	Sitka spruce
Pinus monticola Dougl.	Western white pine
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Thuja plicata Donn	Western red cedar
Tsuga heterophylla (Raf.) Sarg.	Western hemlock

Shrubs

Gaultheria shallon Pursh	Salal
Menziesia ferruginea Smith	False azalea
Ribes bracteosum Dougl.	Stink current
Rubus spectabilis Pursh	Salmonberry
Sambucus racemosa L.	Red-berry elder
Vaccinium alaskaensis Howell	Alaskan blueberry
Vaccinium ovalifolium Smith.	Oval-leaved huckleberry
Vaccinium ovatum Pursh	Evergreen huckleberry
Vaccinium parvifolium Smith	Red huckleberry

Herbs

Adenocaulon bicolor Hook.	Silver-green
Adiantum pedatum L.	Maidenhair fern
Athyrium filix-femina (L.) Roth.	Lady fern
Blechnum spicant (L.) With.	Deer fern
Carex sp.	Sedge
Claytonia sibirica L.	Siberian spring beauty
Dryopteris austriaca (Jacq.) Woynar	Shield fern
Galium triflorum Michx.	Sweat-scented bedstraw
Gymnocarpum dryopteris (L.) Newm.	Oak fern
Listera cordata (L.) R.Br.	Twayblade
Lysichitum americanum Hulten & St. John	Skunk cabbage
Maianthemum dilatatum (Wood) Nels. & Macby.	Two-leaved false Solomon's-seal
Moneses uniflora Gray	One-flowered wintergreen
Oplopanax horridum (J.E. Smith) Miq.	Devil's club
Polystichum munitum (Kaulf.) Presl	Sword fern
Scirpus sp.	Bulrush
Streptopus amplexifolius (L.) DC.	Twisted stalk
Tiarella laciniata Hook.	Cut-leaved foamflower
Tiarella trifoliata L.	Trifoliate-leaved foamflower
Trillium ovatum Pursh	Western trillium
Veratrum viride Ait.	Indian hellebore

CARNATION CREEK
LOGGING AND SILVICULTURAL TREATMENT PROGRAM

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ABSTRACT

Logging and silvicultural activities in the Carnation Creek Watershed Study were monitored to aid researchers in the analysis of results of these treatments on aquatic environments and fish populations. Over the period 1975 to 1981, 41% of the watershed was logged with a range of streamside treatments.

The Carnation Creek watershed is a small west coast British Columbia watershed that is subject to rapid flushing of heavy precipitation (260 to 350 cm/year). Mature trees present were predominantly western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and amabilis fir (*Abies amabilis*), along with a lesser volume of Douglas-fir (*Pseudotsuga menziesii*) on southerly aspects, western white pine (*Pinus monticola*) around Mount Blenheim, Sitka spruce (*Picea sitchensis*) along alluvial floodplains, and a narrow band of red alder (*Alnus rubra*) along the creek.

MacMillan Bloedel became involved with the Carnation Creek project in 1970 with the selection of the watershed to do an in-depth study on the effects of logging and forestry practices on a west coast salmonid stream.

There are three phases to the project:

1. **1970 to 1975—prelogging baseline study.**
2. **1975 to 1981—six winters of logging activities.**
3. **1981 to 1984—postlogging recovery period.**

PLANNING

During the 1970 to 1975 period, intensive planning was conducted:

1. To clarify overall types of activities and treatments to be monitored.
2. To field examine site-specific items relating to planned logging.

As Carnation Creek is within Tree Farm Licence 21, MacMillan Bloedel's logging activities are governed by legislation and operating rules administered by the B.C. Forest Service. Five-year logging plans are submitted for review by the B.C. Forest Service, as well as Federal Fisheries and B.C. Ministry of Environment. Specific two-year cutting permit applications are handled in a similar manner. All five-year plan and cutting permit application logging and road construction proposals are first reviewed by the Carnation Creek Working Group, prior to submission to the Forest Service.

The specific logging goals of the Carnation project were approved, with the concept of "normal" logging techniques being used except where the intent of the study required variances. In operational activities, the intention was to utilize the experimental approach and maximize the information on processes causing effects, rather than just monitor the end result of logging. And to do this, the plan was to attempt to produce significant measurable effects by using, in addition to normal logging practices, a range of treatment intensities and, therefore, produce measurable effects greater than natural variability. These variances from normal logging are significant to the Carnation project and will be referred to further in subsequent parts of this report.

Specific goals established were:

1. Log as rapidly as possible to intensify effects. (This was to be accomplished with logging over 40% of the watershed within six years.)
2. Log both sides of the stream at once in one part of the watershed to give data on the effects of that type of practice. (This was not, and is not, normally allowed on this kind of creek.)
3. Log with the full range of stream margin treatments to obtain data on the effects of each:
   a. Leave a variable width margin of vegetation untouched along the stream.
   b. Log totally to stream edge; remove minor vegetation.
   c. Log merchantable trees from 10 m margin; retain minor vegetation.

Beyond these three parameters, stream margins in other logged openings were considered as "normal" treatments.

ROAD CONSTRUCTION

Roads were developed into the watershed from three directions—Ritherdon Road from the north, Branches 700 and 865 from the east, and Branch 640 from the south. Due to topographical and logistical reasons, the majority of the roads are located on the sidehill and well away from the main creek. No bridges were built across the main creek.

Roads were built generally one year or more prior to logging. The majority of construction took place in the winter months when equipment could not be used at higher elevations. Significant drainage crossings were discussed on a site-specific basis prior to construction.

Normal equipment and techniques included:

- Yarding R/W logs with D-8 cat or rubber-tired skidder.
- Building subgrade with D-8 cat or Poclain shovel.
- Drilling rock with tank-mounted drill and blasting.
- Ballasting and finishing.
- Culvert installation at watercourses with either 61 cm and larger corrugated steel pipes or cedar logs.

Road construction began in late 1974 with the extension of Ritherdon Road into the watershed.

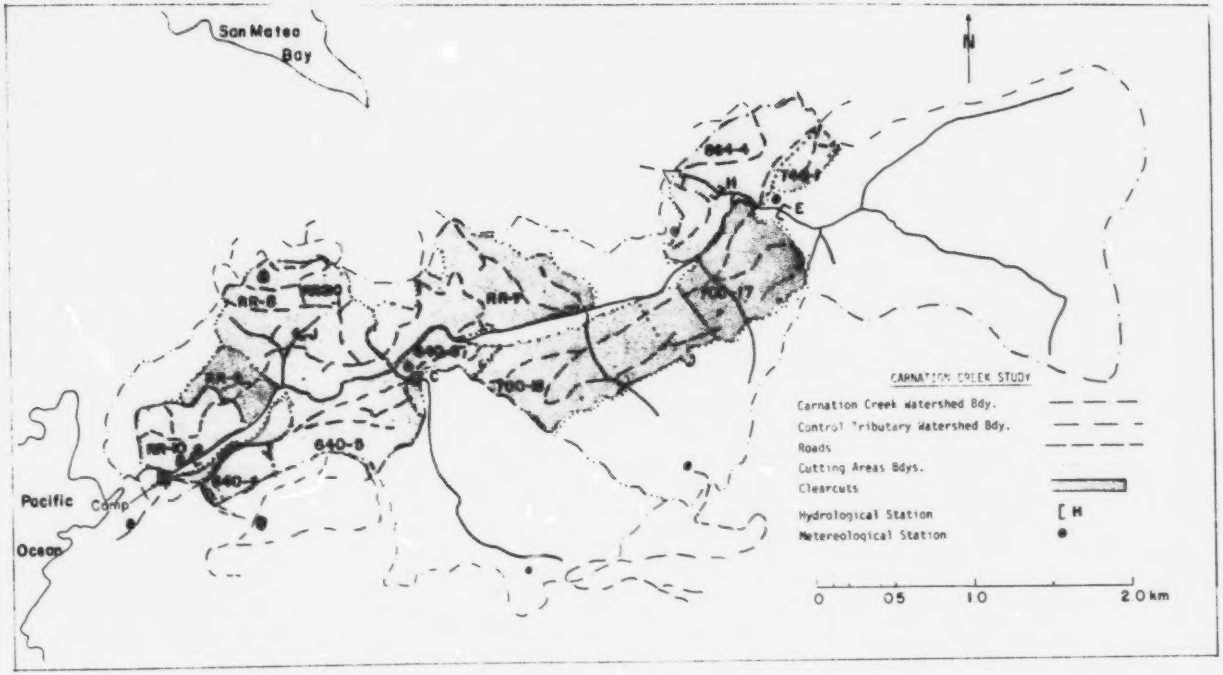
LOGGING

Due to the practice of logging high-elevation, heavy-snowpack sites elsewhere during the summer period, normal logging operations in Carnation Creek and the surrounding area is conducted during the September to May period. During this "winter" period, snowpack throughout the majority of the watershed is light or nonexistent.

Falling and bucking has normally started on specific sites in September and followed by yarding, loading, and hauling from November onward. Yarding systems are predominantly high lead with Madill mobile spar units and with grapple yarders. Of the logging done to date, approximately 55% has been done by mobile high lead spar, 20% by grapple yarder, and 25% by direct loading from the road right-of-way. Topography, soil moisture, and soil conditions in the watershed generally are not conducive to rubber-tired skidder operations.

Logging trucks hauled their approximately 71 ton loads predominantly via the Ritherdon Mainline and the Branches 700 and 865 road systems to the Spencer Creek log dump; loads from the Branch 640 road system were hauled to the Sarita Dryland Sort.

Normal logging techniques, i.e., those practices generally approved by regulatory agencies under current conditions, were the rule for the majority of Carnation Creek. One major departure from the


San Mateo
Bay
N
Pacific
Ocean
Camp
RR-8
RR-7
RR-10
640-5
700-18
700-17
H
E
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CARNATION CREEK STUDY
Carnation Creek Watershed Bdy.
Control Tributary Watershed Bdy.
Roads
Cutting Areas Bdys.
Clearcuts
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0.5
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Carnation Creek watershed showing the main stem and tributaries, and the location of clearcuts, hydrological stations, and meteorological stations.

"normal" must be taken into consideration when the impacts on other resources are examined. Specifically, this was the introduction of a much severer streamside treatment so that its effects on stream siltation, water temperature, and other aspects could be analyzed. Therefore, the RR-8/640-5 openings, logged during 1976-1977, had the standard "P-1" stream protection clause waived, and the following took place:

- Trees felled across the creek.
- Rotten windfalls in or across the creek were broken into smaller pieces during felling and yarding.
- Merchantable windfalls in the creek, plus felled trees across the creek, were yarded out.
- All remaining submerchantable trees along the creek were felled.
- Logging occurred simultaneously on both sides of the creek.

Following this, the remaining smaller diameter debris and larger diameter broken chunks were left as is in stream and, in subsequent storms, were deposited in debris jams downstream.

The impacts of this severe treatment on downstream resources and sampling sites must be considered when analyzing data from the Carnation Creek project.

A summary of logging and postlogging treatments by individual setting is found in Table 1.

Logging opening size ranged from 7.3 ha to 63.5 ha; between 1975 and 1981, 404 ha, or 41% of the watershed, was logged—the major unlogged areas remaining being the upper drainage above "E" weir and the control area above "C" weir.

SILVICULTURAL TREATMENTS

To minimize the invasion of logged openings by alder, alder seed trees adjacent to streams were treated either by herbicide or by felling/girdling. Treatments were completed one year prior to logging or immediately following logging. Details on these and subsequent treatments are detailed by logging area in Table 1. No alder seed tree control was practiced along the RR-10, RR-9, and 640-4 openings as part of the experimental design. Scarification by D-6 cat with brush blade was successfully used in openings 640-4 and 640-6 along the alluvial flats as a means of windrowing dense slash prior to burning, setting back brush development, and preparing the site for planting. Scarification was also conducted on a streamside area in the upper reaches (700-17) as a means of preparing the site for planting, but slash piles were not burned. Scarification, as a silvicultural tool, has been generally of limited value in west coast watersheds due to limitations of soil type, soil moisture, and topography. No other scarification was feasible at Carnation Creek.

The major means of site preparation used was broadcast slash burning, either by manual lightup or helicopter drip torch. Virtually, all openings on the north side of the creek were treated in this way, with resulting burns of moderate to good coverage. Burns achieved on the alluvial flats were either nonexistent or very patchy at best, due to moist conditions and rapid brush development. Similarly, due to moisture and shade conditions, slopes south of the creek rarely burned effectively, except on steeper ridges.

Reforestation followed normally in the spring after site preparation, particularly for high-site, quality bottomlands and lower slopes, to establish conifers before brush development became severe. Planting of other areas varied up to three years, depending on availability of appropriate planting stock and opportunities for natural regeneration. Species planted were Douglas-fir, western hemlock, Sitka spruce, western red cedar, and amabilis fir, as well as experimental quantities of grand fir (*Abies grandis*).

LOGGING AND SILVICULTURAL TREATMENT PLANS

The years 1981 to 1984 make up the period in which no road construction or logging activities will take place, allowing completion of studies relating to the watershed's recovery from disturbance.

Despite this, silvicultural treatments such as slash burning and planting will continue until completion in 1983:

- Landing burns, 700-17, 700-18—fall 1982.
- Broadcast burn, RR-6—fall 1982.
- Planting, 700-17, 700-18, RR-6—spring 1983.

In addition to these, herbicide treatment of dense salmon berry (*Rubus spectabilis*), red alder, and other brush species are required to free established conifers from suppression. An aerial spray, using a herbicide of extremely low toxicity to fish (Krenite), is planned for fall 1982 on the alluvial flats and lower slopes of the earliest clear-cut openings—RR-10, RR-8, and 640-5. (Subsequent to the meeting when this paper was presented, the use of Krenite was discontinued as a result of regulations. The company will carry out spray work with another herbicide.) Herbicide treatments in years following are anticipated on portions of the rest of the alluvial flats and lower slopes, but are of less need in most of the valley.

Road construction and logging activities are planned to resume by early 1985, particularly in the upper slopes above "E" weir.

REFERENCE

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Table 1. Summary of Logging and Postlogging Treatments—MacMillan Bloedel Limited, Cameron Division.

Area Name	Logging**	Streamside Treatment	Slash Treatment	Reforestation*
RR-10	1975 to 1976 (23.5 ha)	- Leave strip left along creek with major and minor vegetation intact (wider zone left along canyon). - No alder seed tree treatment.	- Broadcast burn with helicopter drip torch, fall 1976. - Patchy burn accomplished on slopes; light intensity. - No burning accomplished on alluvial flats.	- Spring 1977—alluvial flats only (S, C). - Spring 1978—(S, C, H, F). - Spring 1979—(H).
RR-9	1980 to 1981 (16.2 ha)	- Leave strip left along creek with major and minor vegetation intact. - No alder seed tree treatment.	- Broadcast burn, manual lightup, fall 1981. - Complete burn coverage; light intensity. - Patchy burn on alluvial flats.	- Spring 1982—complete setting (F, C, S).
RR-8	1976 to 1977 (61.0 ha)	- No leave strip left along creek. - Trees felled and yarded across creek. - Alder seed trees "hacked & squirted" with Tordon 22K in 1975.	- Broadcast burn with helicopter drip torch, fall 1977. - Good burn achieved on majority of upper slope; light to moderate intensity. - No burning accomplished on alluvial flats and portions of lower slope. - Small portion reburned in slash-burn escape, fall 1979.	- Spring 1978—alluvial flats, lower slopes only (S, C, H, F, Bg). - Spring 1979—(F). - Spring 1980—(F).
RR-810-1	1977 to 1978 (7.3 ha)	- Not applicable.	- Broadcast burn, manual lightup, fall 1978. - Complete burn coverage; moderate + intensity. - Eastern portion reburned in slash-burn escape, fall 1979.	- Spring 1979—(F). - Spring 1980—(F).

Table 1. (continued)

Area Name	Logging**	Streamside Treatment	Slash Treatment	Reforestation*
RR-7	1978 to 1979 (63.5 ha)	· Merchantable trees removed from creekside; some minor vegetation left. · Leaning trees along creek pulled back with lines from yarder or felled with jacks. · Large alder seed trees blew down in storm; number of smaller alders felled; 1979.	· Broadcast burn, manual lightup, fall 1979. · Complete burn accomplished on slopes; moderate + intensity. · Patchy burn accomplished on alluvial flats.	· Spring 1980—complete setting (F, C, S).
RR-6	1980 to 1981 (1.5 ha)	· Not applicable.	· Planned broadcast burn, fall 1982, with larger opening outside watershed.	· Planned planting, spring 1983.
864-4	1977 to 1978 (48.2 ha)	· "Normal" treatment—"P-1" clause in effect. · Leave strip left along creek due to topography. · Alder seed trees "hacked & squirted" with Tordon 22K in 1978.	· Broadcast burn, manual lightup, spring 1979; area NE of "H" creek only. · Light intensity broadcast burn achieved. · Landing and roadside accumulation burn, fall 1979; area SW of "H" creek only.	· Spring 1979—flats only (C, Ba). · Spring 1980—(F, C). · Spring 1981—(F, H, C, Ba).
700-18	1979 to 1980 (51.1 ha)	· "Normal" treatment—"P-1" clause in effect. · Wide leave strip left along creek due to canyon. · No alder seed tree treatment.	· No burning to date; large roadside landings planned for burning, fall 1982.	· Spring 1982—lower slopes only (H). · Upper slopes partially stocked with natural regeneration; remainder planned for planting, spring 1983.
700-17	1980 to 1981 (53.9 ha)	· "Normal" treatment—"P-1" clause in effect. · Heavy leaners and nonmerchantable trees left within 10 m zone. · Alder seed trees "hacked & squirted" with Tordon 22K in 1978; smaller alder trees felled in 1981.	· No burning to date; large roadside landings planned for burning, fall 1982. · Flats adjacent to creek scarified, fall 1981, by D-6 cat with brush blade.	· Spring 1982—flats and lower slopes only (C, H). · Upper slopes planned for planting, spring 1983.

Table 1. (continued)

Area Name	Logging**	Streamside Treatment	Slash Treatment	Reforestation*
740-1	1979 to 1980 (8.5 ha)	· Not applicable.	· No slash treatment.	· Spring 1982–(Ba). · Portions of setting are fully stocked with natural regeneration.
640-4	1978 to 1979 (19.4 ha)	· Leave strip left along creek with major and minor vegetation intact (wider zone left along canyon portions). · No alder seed tree treatment.	· Alluvial flats adjacent to creek scarified, spring 1979, by D-6 cat with brush blade. · Broadcast burn of slopes and scarification piles done, fall 1979, by helicopter AID dispenser and manually. · Patchy and light intensity burn achieved.	· Fall 1979–alluvial flats (S). · Spring 1980–alluvial flats and lower slopes (S, C, H). · Spring 1981–(H, C).
640-5	1976 to 1977 (35.6 ha)	· No leave strip left along creek. · Trees felled and yarded across creek. · Alder seed trees "hacked & squirted" with Tordon 22K in 1975.	· Broadcast burn with helicopter drip torch; fall 1977; unsuccessful. · Attempts to reburn in fall 1977 and 1979 gave only patchy accumulation burns on upper slopes.	· Spring 1978–alluvial flats only (S, C). · Spring 1979–(S). · Spring 1980–(C, H). · Spring 1981–(C).
640-6	1978 to 1979 (14.2 ha)	· Merchantable trees removed from creekside; most of minor vegetation left. · Large alder seed trees blew down in storm; number of smaller alders felled, 1979.	· Alluvial flats adjacent to creek scarified, spring 1979, by D-6 cat with brush blade. · Broadcast burn of slopes and scarification piles done, fall 1979, manually. · Patchy, light intensity burn achieved.	· Fall 1979–alluvial flats (S). · Spring 1980–alluvial flats (S). · Spring 1982–(H). · Portions of upper slope are fully stocked with natural regeneration.

* Planted Species Abbreviations:

F = Douglas-fir
C = Western Red Cedar
H = Western Hemlock
S = Sitka Spruce
Ba = Amabilis Fir
Bg = Grand Fir

** Total hectares includes road right-of-way.

QUESTIONS
TO J. DRYBURGH

Question *(unidentified)*: What would be the normal expectation for return to that watershed to start logging again?

Answer *(unidentified)*: We're taking a look at five years, or were you referring to rotation?

Question *(unidentified)*: Well, the remaining area is what I had in mind. I see that 41% is logged.

Answer *(J. Dryburgh)*: 1985 is when we'll be starting back.

Question *(unidentified)*: At that point, do you consider your regeneration adequate to prevent whatever kind of erosion problems might be suspected from increasing the cut.

Answer *(unidentified)*: We don't anticipate any erosion problems, per se.

Comment *(C. Scrivener)*: We might point out that a fairly good swamp in the watershed is within what was called the 30-year fire break. So I imagine there will be an introduction of logging activities again 20 years from now, as that strip is taken out. That covers most of the north-facing slope right under the control watershed, in C tributary.

A FIRST LOOK
AT LOGGING EFFECTS ON THE HYDROLOGIC REGIME OF CARNATION CREEK EXPERIMENTAL WATERSHED

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INTRODUCTION

The Carnation Creek Experimental Watershed Project, initiated in 1970 to study logging effects on a small west coast salmonid stream (Hartman 1981), included three periods: 5 years prelogging calibration, 6 years logging, and at least 3 years postlogging. This paper describes the results of some preliminary analyses of logging effects on the hydrologic regime of the watershed: specifically, annual water yield, slope and valley bottom groundwater levels, storm hydrograph peak flow and time-to-peak characteristics, and summer low flows. The analyses focus on both the main creek and a small 12 ha tributary watershed.

The Carnation Creek project is the major of three longer-term watershed studies of logging effects on stream systems in coastal British Columbia (CNCIHD 1971, Cheng et al. 1975). Additional studies of logging impacts on coastal streams in Oregon (Rothacher 1973, Harr et al. 1975, Harr et al. 1979, Harr 1980) and California (Ziemer 1981) provide a context within which Carnation Creek results can be assessed.

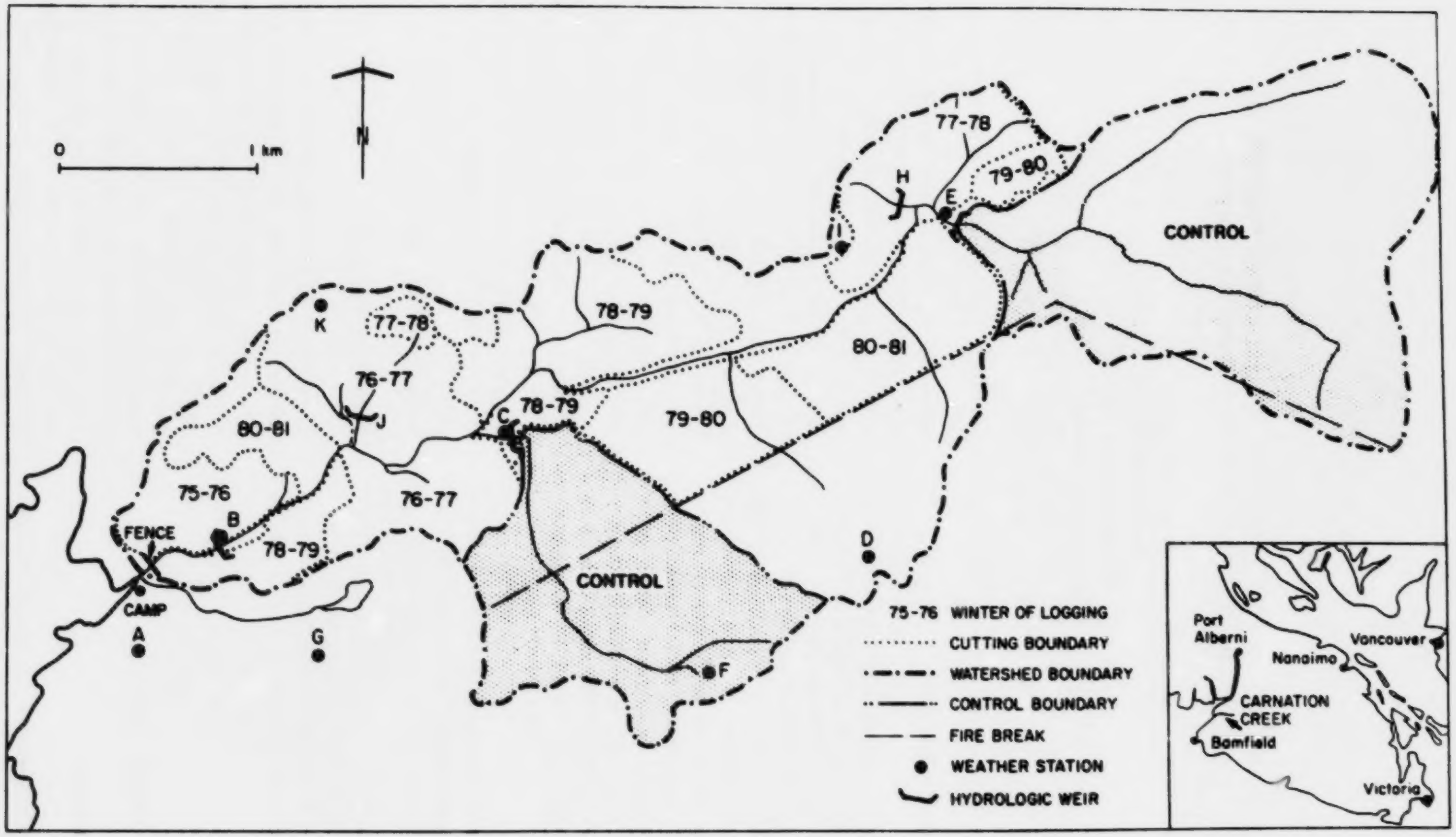
STUDY AREA

Watershed Characteristics

The Carnation Creek watershed is located on the west coast of Vancouver Island near Bamfield, British Columbia (Fig. 1). The basin area of 9.5 km^2 features rugged terrain from sea level to 880 m elevation with steep slopes, of 40% to over 80%, and a relatively wide valley bottom through which the main stream meanders. Slope soils, underlain by watertight bedrock of volcanic origin, are coarse colluvial materials of gravelly loam to loamy sand texture with a moderately thick organic layer and are classified as ferro-humic podzols (Oswald 1973). They are shallow, having an average depth of about 70 cm, remain moist year-round, and are highly permeable. The valley bottom contains mostly alluvial sands and gravels. The forest is comprised of old-growth western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), amabilis fir (*Abies amabilis* (Dougl.) Forbes), and western red cedar (*Thuja plicata* Donn), with some Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on drier sites, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in the valley bottom, and red alder (*Alnus rubra* Bong.) along the stream margin (Oswald 1973).

Climate and Streamflow

The climate of the watershed is influenced by the adjacent Pacific Ocean and features mild, wet winters (characterized by frequent frontal storms) and mild summers. Annual precipitation is mostly rain and ranges from about 210 cm to over 480 cm (Table 1), over 75% falling in October to March (Fig. 2). Some snow occurs at high elevations in most years but it usually disappears quickly. Annual water yields ranged from 210 cm to 400 cm and measured flows from less than 0.03 m^3/s to 44.3 m^3/s. Streamflow closely followed the precipitation pattern (Fig. 2) and exhibited flashy storm runoff, although overland flow was rare in undisturbed areas. Precipitation was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75-76 WINTER OF LOGGING
CUTTING BOUNDARY
WATERSHED BOUNDARY
CONTROL BOUNDARY
FIRE BREAK
WEATHER STATION
HYDROLOGIC WEIR
Port Alberni
Nanaimo
Vancouver
CARNATION CREEK
Bamfield
Victoria

Fig. 1. Carnation Creek watershed showing location of hydrometeorological stations and clear-cut logging boundaries.

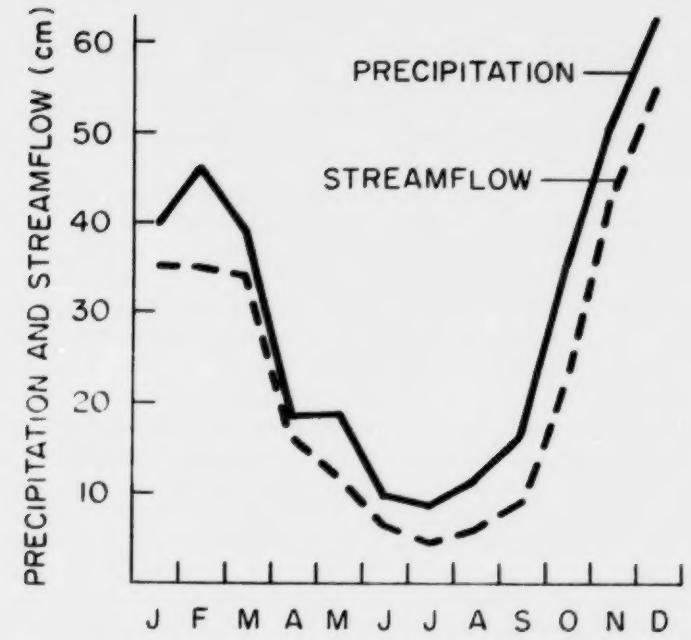

Fig. 2. Average monthly precipitation at station F and streamflow at B weir, expressed as a depth over the watershed (1973 to 1980).

Table 1. Annual precipitation (cm) at stations A and F, based on October-September water year (1972 to 1980).

Water Year	A	F	Water Year	A	F
1972-1973	245	313	1976-1977	223	286
1973-1974	385	487	1977-1978	268	346
1974-1975	250	299	1978-1979	207	265
1975-1976	381	488	1979-1980	261	340

Table 2. Characteristics of gauged watersheds in Carnation Creek basin.

Weir	Drainage Area (ha)	Elevation Range (m)
B	930	8-884
C	145	46-700
E	264	150-884
H	12	152-305
J	24	30-300

measured at 9 sites and streamflow at 5 weirs (Fig. 1). Characteristics of the gauged areas are given in Table 2. Watersheds C and E remained unlogged and served as controls for evaluating flow changes at the other weirs. Groundwater levels were also measured, using piezometers, in the main valley bottom southwest of J weir to monitor changes in summer recession characteristics and on the slopes of H watershed to monitor changes in storm peaks (Symons 1978). To avoid damage, piezometers were cut to ground level and capped prior to logging.

WATERSHED TREATMENTS

Logging activity in Carnation Creek was initiated in 1975 and completed in 1981 (MacMillan Bloedel Limited 1979), timber being harvested in clear-cut patches ranging from 7 to 95 ha (Fig. 1), for an accumulated total clear-cut area above B weir of 40% (Table 3). Logging took place in winter by high-lead or grapple cable-yarding techniques. Prescribed slash burning was usually carried out in the early fall, about one-half of the total clear-cut area being effectively burned, and some portions of the valley bottom were scarified. Planting was done in early spring.

In H watershed, road construction took place in early 1976, one lower slope road redirecting intercepted seepage water to the stream channel near its source. The road surface area was about 6.5% of the total watershed. About 90% of H watershed was clear-cut during the winter of 1977-1978 and 35% (one slope) slash burned in April 1979 and planted in early 1980. Roads, logging, and burning exposed or disturbed mineral soil over about 23% of the watershed (Smith, R.B., personal communication, 1982).

DATA ANALYSIS

Comparisons were between logged and unlogged watersheds or areas. For streamflow, changes in logged area data were accepted as valid when relationships with both controls (C and E) concurred. Data from J weir were not available. Simple linear

Table 3. Accumulated percent of Carnation Creek watershed above B weir clear-cut from 1975 to 1981.

Year	1975	1976	1977	1978	1979	1980	1981
% clear-cut	0	1	11	17	27	33	40

regressions were fitted to the data, statistical tests being used to judge the significance at the 5% level of differences in means (covariance analysis) or slopes (F-test). Where the number of values was small and inordinately large changes would have been required to show statistical significance, changes are given without statistical justification and the broad confidence bands not shown on the diagrams.

Annual water yields were summed by water year (October to September) and postlogging values compared to the prelogging regression line, the 1980-1981 annual water yields being estimated from nine months of data. Changes in annual evapotranspiration in H watershed, computed as differences between annual precipitation and runoff, were similarly assessed, precipitation estimates being averages of station I and E values. Adequate precipitation estimates were not available to apply this second method to B weir data.

Peak slope groundwater levels at two sites in the logged area of H watershed were compared with levels from a nearby unlogged site for three periods: before disturbance, after road construction, and after harvesting. A simple bar graph was derived from the regressions for a major hypothetical storm level at the control site.

Storm hydrograph characteristics were determined by Hewlett and Hibbert's (1967) method of separating rapid storm runoff or quickflow from slower delayed flow. The initial rise of the hydrograph occurred when the rate of increase in streamflow exceeded 0.55 L/s/ha/h, peak flow was maximum discharge for the storm less discharge at initial rise, and time-to-peak was from initial rise to peak flow. For the logged watersheds B and H, most peaks were below 17 m^3/s and 0.28 m^3/s, respectively. For multiple-peaked hydrographs, individual peak flow events were separated if possible or the multiple hydrograph was excluded from the analysis. An attempt was made to include rain-only storms, and a few storms suspected of involving significant snow were omitted. July 1972 to January 1976 served as the calibration period for B weir, yearly postlogging data sets being chosen on a February-to-January basis to match approximately the end of falling and start of yarding each winter. Three periods were selected for H weir: December 1972 to January 1976 for calibration, February 1976 to September 1977 for roads only, and June 1978 to April 1981 for postlogging.

Valley-bottom groundwater levels at one site, chosen solely from periods of declining water level and streamflow, were regressed on flows at B weir for the five summers (June to September) 1976 to 1980. Water levels corresponding to a flow of 0.09 m^3/s were determined from the yearly regressions and plotted. Results obtained using flow data from the controls C and E were similar and are not shown.

Summer low-flow data for logged and unlogged watersheds were compared using minimum July to September daily flows and the number of July and August days with streamflow below predetermined levels. A low-flow day (Harr and Krygier 1972) was defined as having a mean flow less than 0.07 m^3/s at B weir, with corresponding values at the other three weirs. Postlogging data were related to prelogging regressions.

RESULTS

Annual Water Yield

For the logged H watershed, most postlogging annual water yield values lie above the prelogging regression lines (Fig. 3a, b). Examination of water yields from all weirs and quantitative comparisons of postlogging control data with a prelogging regression of control C on control E data (not shown) suggest that the annual water yield values for C weir are about 41 cm too high for 1978-1979 and 34 cm too low for 1979-1980 and that the 1980-1981 E weir value is 56 cm too high. If these adjustments were made, all postlogging points would lie above the regression lines of Fig. 3a, b. In addition, postlogging evapotranspiration was lower (Fig. 4), a change in evapotranspiration being construed as a change in water yield. Differences between the original and adjusted postlogging points and the regressions of Figs. 3a, b and 4 are given in Table 4. These data suggest that annual water yield from H watershed increased by an average 36 cm, or about 14% of total runoff, in at least two of the three postlogging years.

For the logged watershed above B weir, most postlogging annual water yield values lie below the prelogging regression lines (Fig. 3c, d). A comparison of B weir data with that from the other three weirs suggests that the 1978-1979 value is about 40 cm too low. If this and the above-noted adjustments were made, only the 1980-1981 points would not lie below the regression lines of Fig. 3c, d. The data indicate an average decrease in annual water yield at B weir of at least 20 cm, or about 8% of total

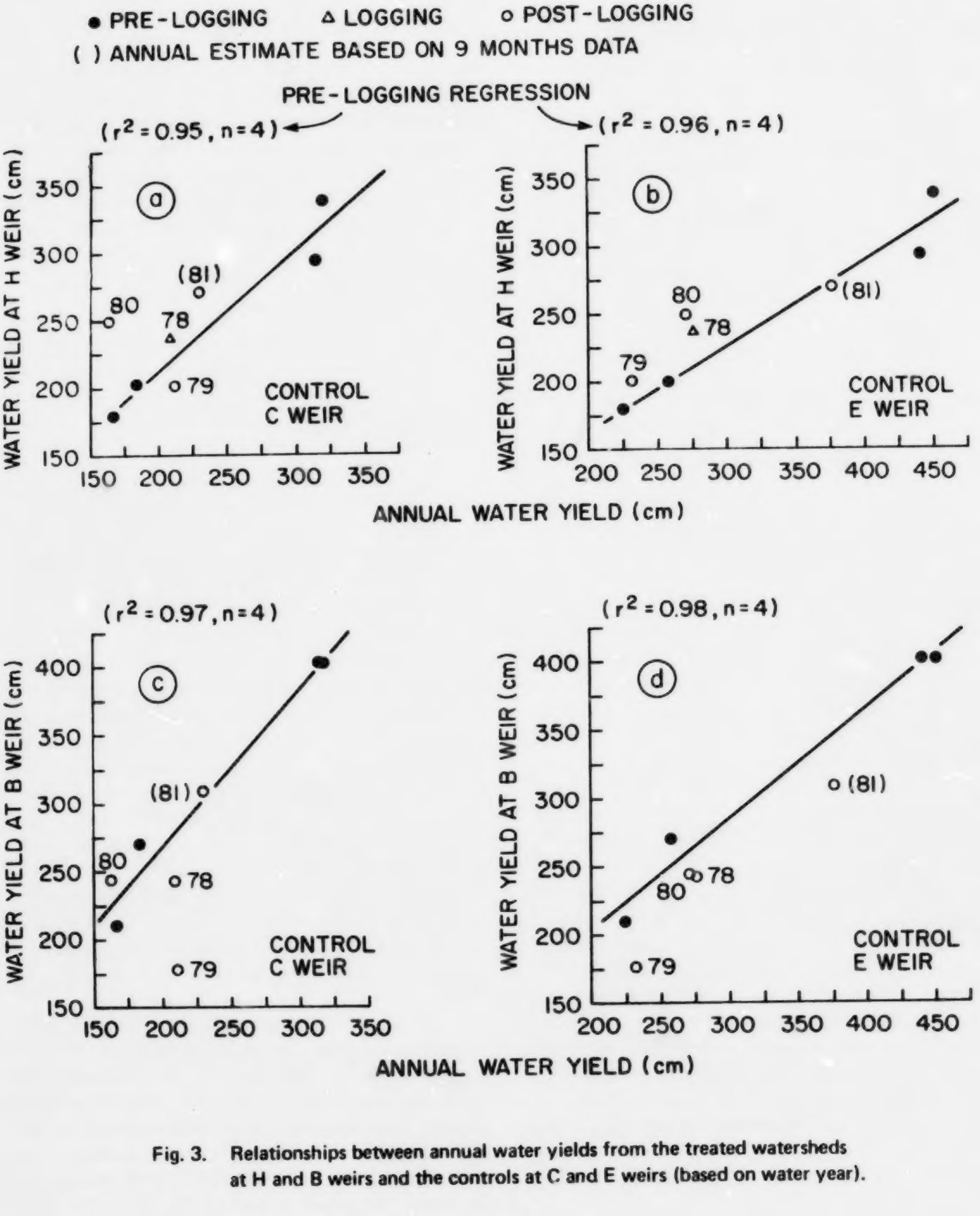

Fig. 3. Relationships between annual water yields from the treated watersheds at H and B weirs and the controls at C and E weirs (based on water year).

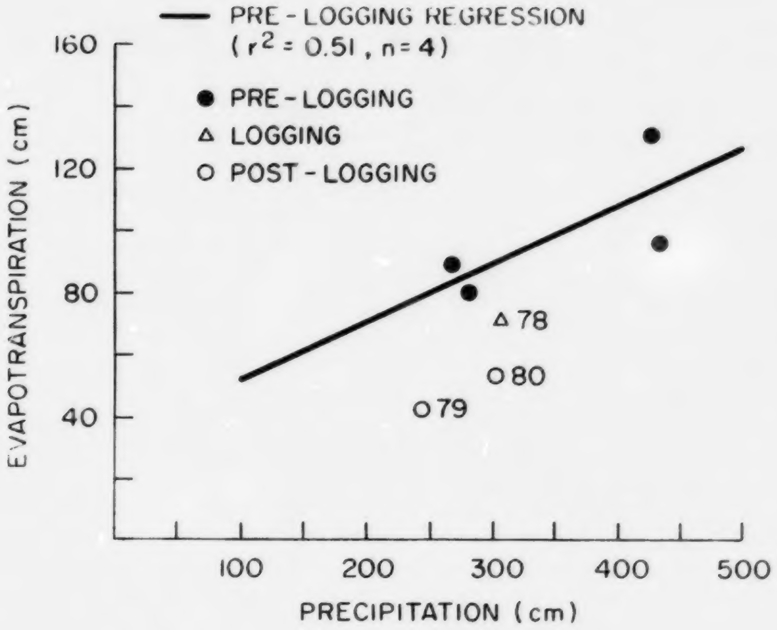

Fig. 4. Relationship between annual precipitation and evapotranspiration for H watershed (based on water year).

Table 4. Estimated postlogging changes in annual water yield at H and B weirs and annual evapotranspiration for H watershed.

Source	Water Year			
	1977-1978	1978-1979	1979-1980	1980-1981
	cm			
H-weir				
Fig. 3(C)	17	-21 (16)	71 (41)	31
Fig. 3(E)	26	17	41	-3 (31)
Fig. 4(ET)	20	38	36	----
B-weir				
Fig. 3(C)	-35	-103 (-14)	21 (-20)	5
Fig. 3(E)	-23	-53 (-13)	-19	-39 (6)

( ) adjusted value

runoff for three years, and a possible marginal increase in 1980-1981, the last year of logging (Table 4).

All postlogging points fall within broad 95% confidence bands for all prelogging regressions in Figs. 3 and 4.

Storm Runoff

Storm runoff is rapid in the Carnation Creek watershed. For example, streamflow increased from 2.5 m^3/s to 44.3 m^3/s in only 7 hours in the maximum recorded storm at B weir. During another major midwinter storm, streamflow in H watershed followed rainfall variations closely and quickflow was equivalent to over 90% of the precipitation (Fig. 5). Midslope groundwater levels also responded almost instantaneously to rainfall intensity fluctuations, with vertical soil-water flow rates exceeding 40 cm/h (Fig. 5). From observations in soil pits and along road cut slopes, it appears that much of this rapid transmission of water from the surface to the groundwater table is through macrochannel networks which bypass the soil matrix. In this old-growth coastal rain forest, these macrochannels are mainly decayed roots.

Road-diverted storm runoff created overland flow below the culvert outfall, causing surface erosion and carrying ditch-eroded soil material to the stream channel.

Slope Groundwater Levels. Peak groundwater levels at one site, located 30 m downslope from a road, decreased significantly after road construction and then increased after harvesting to near prelogging values (Fig. 6). A second site, located directly upslope 15 m above the road, showed no change after road construction but a significant increase after harvesting (Fig. 6). These changes were some of the largest recorded in H watershed.

Peak Flows. In H watershed, peak flows increased significantly after road construction and harvesting (Fig. 7a, b), although the after-road regression with the control C was only significant at the 10% level. The average increase for both periods was 20%, being 11% and 30% after roads and 22% and 19% after logging in relation to controls C and E, respectively. At B weir, peak flows showed no significant change overall (Fig. 8a, b), yearly postlogging regressions being nearly identical. Of the first major postlogging fall storm peaks in the logged watersheds, only the 1979 peaks were significantly different in relation to both controls, being an average 102% higher at H weir but 34% lower at B weir (Figs. 7 and 8).

Anomalies in annual water yield data for the two controls C and E have already been mentioned. To check for postlogging discrepancies in individual storm peaks, regressions linking control weir peaks in pre- and postlogging periods, plus yearly postlogging regressions linking H weir peaks with those from both controls, were fitted (not shown). Statistical tests revealed no significant differences among these regressions.

Time-to-Peak. In H watershed, time-to-peak showed a progressive decrease after road construction and harvesting (Fig. 7c, d), although only the regressions on control C were significantly different for both mean and slope. For prelogging time-to-peak durations of 5 to 30 hours, maximum decreases were 0.5 to 4.6 hours in relation to control C and 0.2 to 1.5 hours in relation to control E.

At B weir, time-to-peak both increased and decreased in relation to the two controls (Fig. 8c, d). Only the slope of the 1980 regression with control C was significantly different, and that appears to be an artifact of the small number of data. There was thus no clear indication of the nature of changes, if any, in time-to-peak for Carnation Creek.

Frequency Analysis. An annual B weir peak flow frequency relationship was obtained by fitting 10 years data (Table 5) to a Gumbel distribution (Fig. 9). The highest recorded peak flow of 44.3 m^3/s has an estimated return period of 14 years. This peak was the first major storm event to occur after yarding activity near the stream (spring 1977) in the large 1976-1977 setting and caused significant changes to the stream channel in this setting.

Valley-Bottom Groundwater Levels

Summer groundwater levels in the alluvial valley bottom increased significantly after harvesting in the lower portion of the Carnation Creek watershed (Fig. 10). The 1977 and 1978 increases occurred after logging of the valley bottom upstream in 1976-1977, while the further 1979 and 1980 significant increases resulted after logging and scarifying the surrounding area in 1978-1979. The actual measurement site was not scarified. During summer, valley-bottom groundwater supplies about 30% to 40% of low flows.

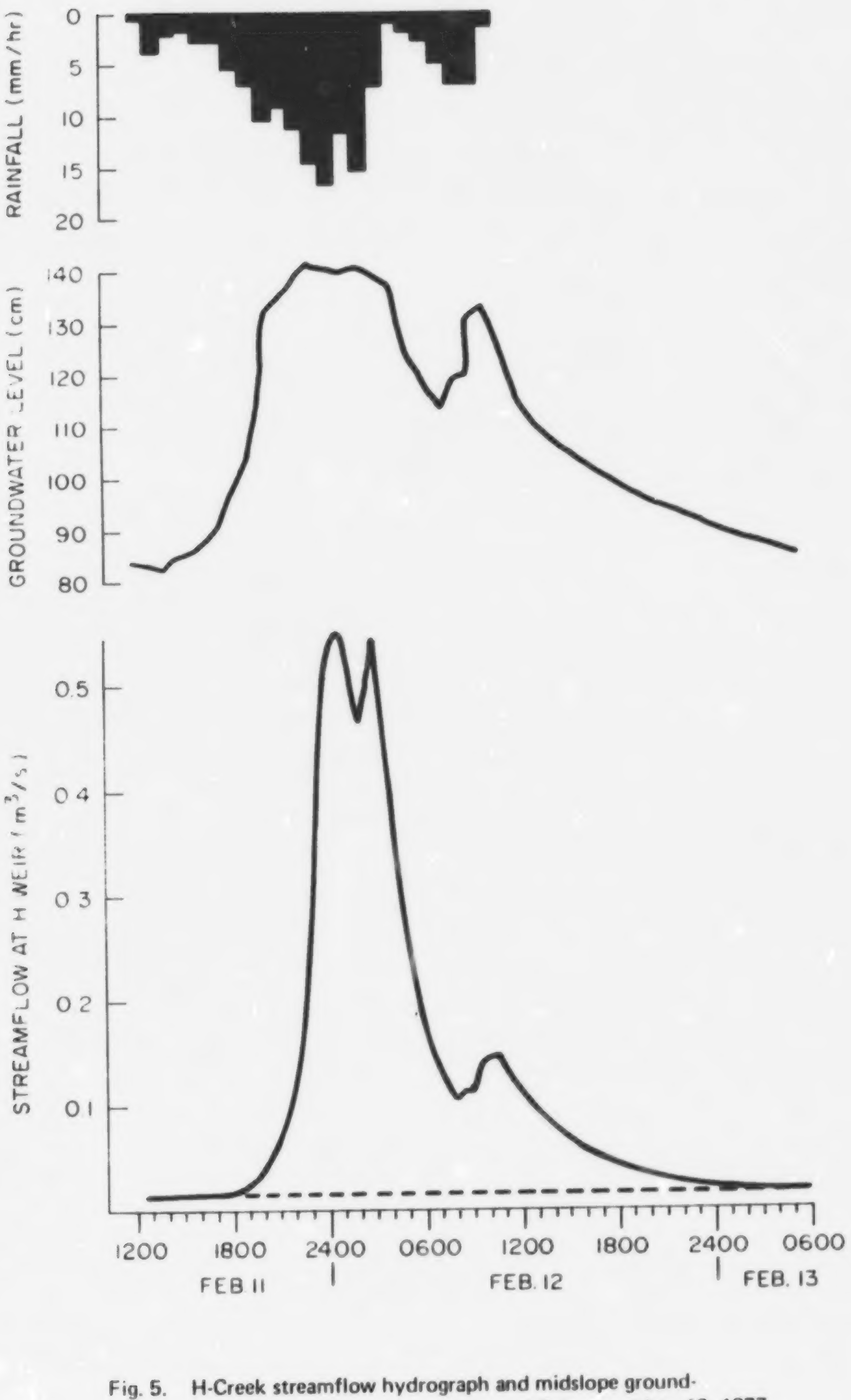

Fig. 5. H-Creek streamflow hydrograph and midslope groundwater level response to rain storm of February 11 to 12, 1977.

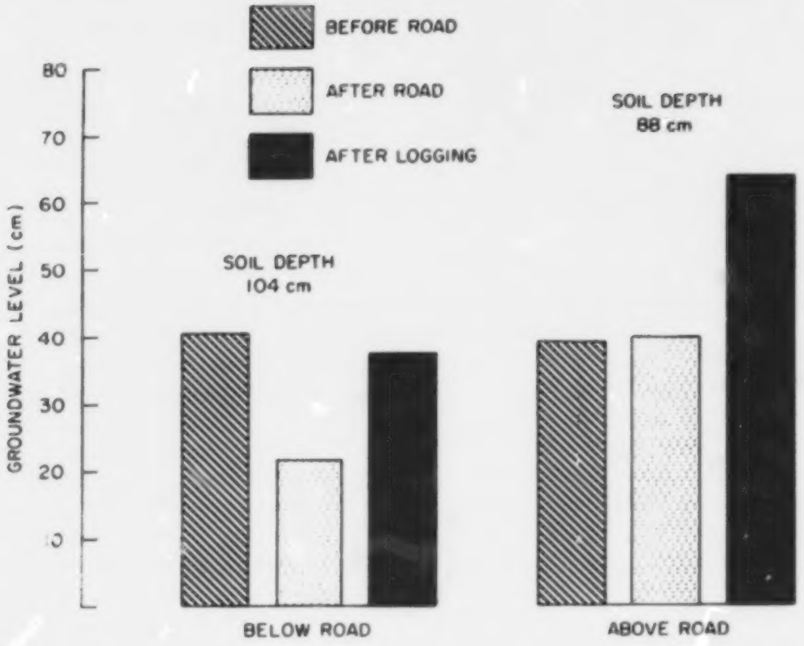

Fig. 6. Comparisons of peak slope groundwater levels at below and above road sites in H watershed for the same hypothetical storm before roads, after road construction, and after logging.

Table 5. Annual peak flows (m^3/s) at B weir based on October-September water year (1971 to 1981).

Water Year	Peak Flow	Month	Water Year	Peak Flow	Month
1971-1972	31.5	Mar.	1976-1977	34.9	Feb.
1972-1973	30.3	Dec.	1977-1978	24.4	Nov.
1973-1974	18.8	Dec.	1978-1979	44.3	Nov.
1974-1975	21.9	Nov.	1979-1980	23.2	Dec.
1975-1976	31.4	Nov.	1980-1981	43.1	Dec.

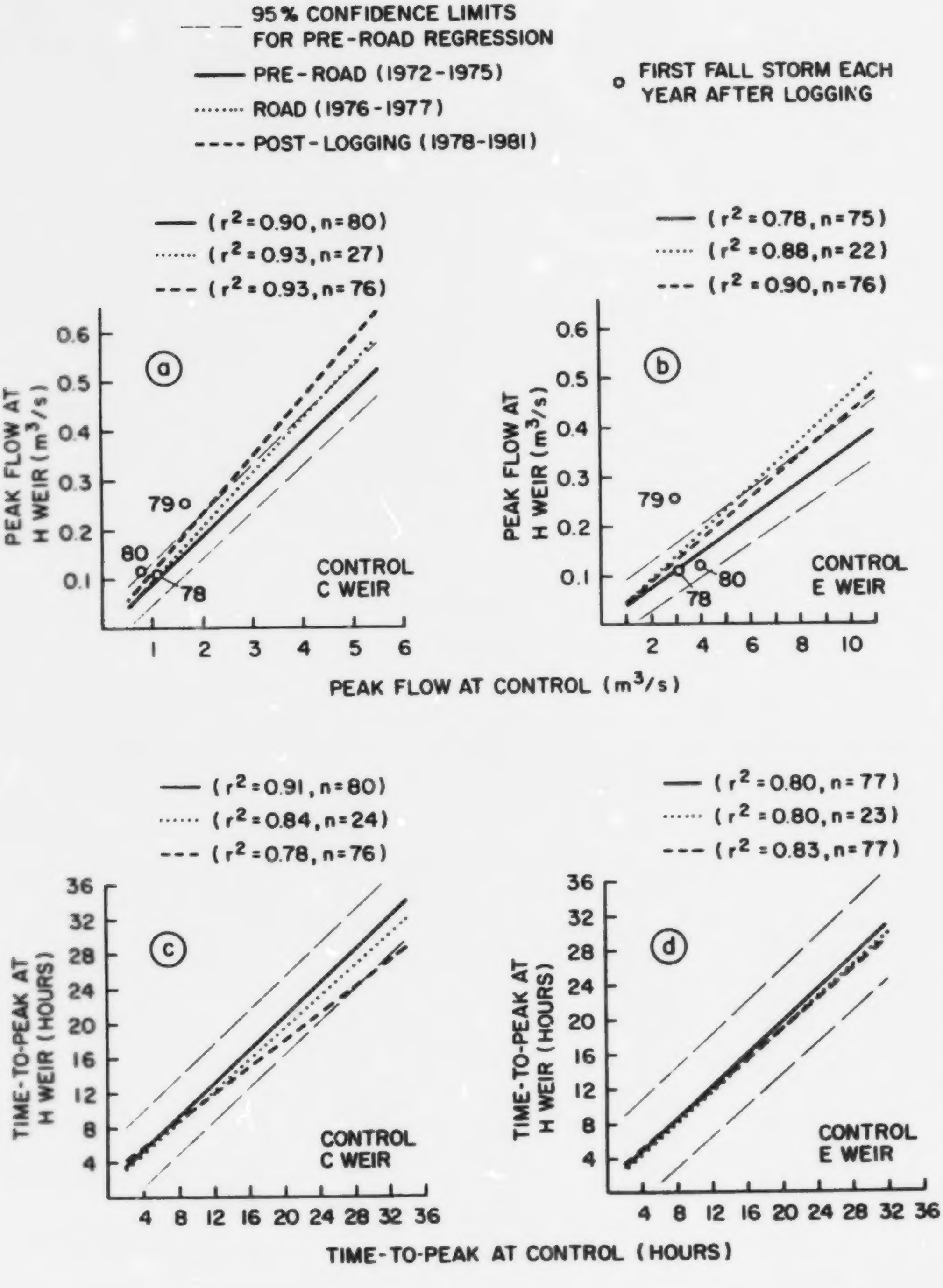

Fig. 7. Relationships for peak flow and time-to-peak storm hydrograph characteristics between H watershed and control watersheds C and E (before logging, after roads, and after logging).

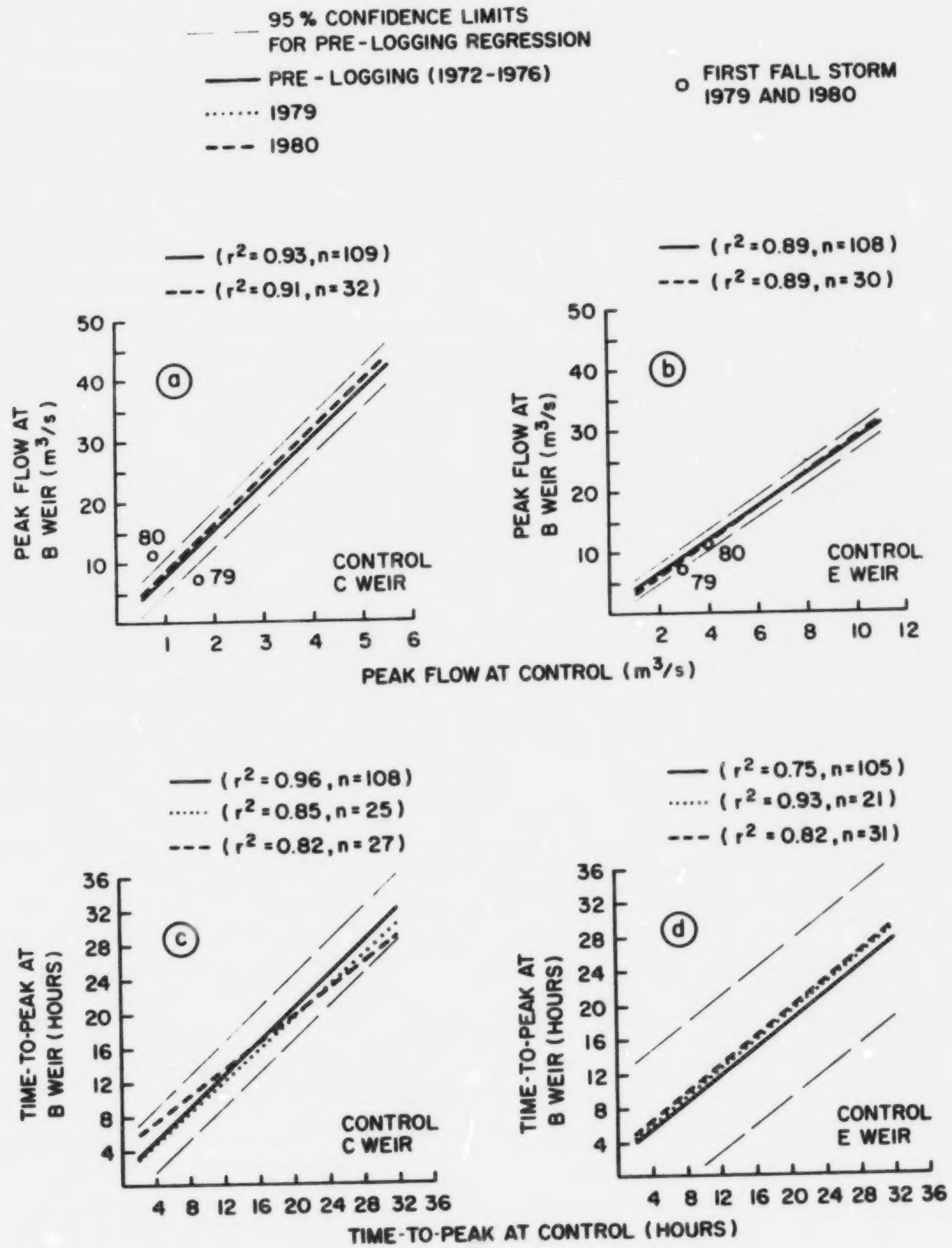

Fig. 8. Relationships for peak flow and time-to-peak storm hydrograph characteristics between Carnation Creek watershed at B weir and control watersheds C and E (before logging, 1979 and 1980).

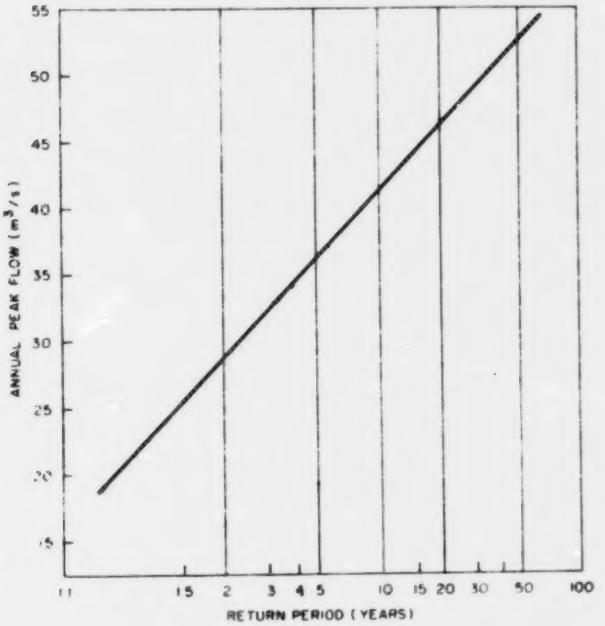

Fig. 9. Gumbel frequency relationship for annual peak flows at B weir, Carnation Creek (1971 to 1981).

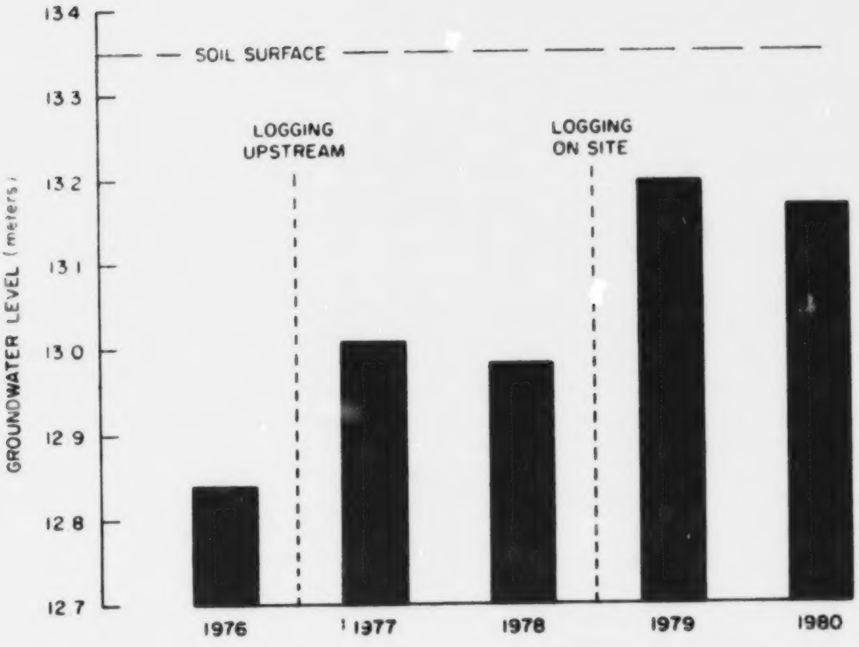

Fig. 10. Pre- and postlogging comparison of summer valley-bottom groundwater levels at one site for a streamflow of 0.09 m^3/s at B weir (1976 to 1980).

Summer Low Flows

In H watershed, minimum daily summer flows increased by an average of at least 78% in 1978 and 1979 (Table 6), the first two postlogging years, but showed no change in 1980. The increases, based on comparisons with prelogging regressions (not shown), are only statistically significant in relation to control E. The number of postlogging low-flow days also decreased in relation to control E (Fig. 11) and control C (not shown). These decreases were greatest in 1978 and 1979, indicating higher low flows, but still fell within the 95% prelogging confidence band.

At B weir, minimum daily summer flows apparently decreased by an average of at least 47% in 3 of the 5 postlogging years (Table 6), but showed little or no change in 1978 and 1980. The number of postlogging low-flow days also increased in 1977 and 1979 in relation to control E (Fig. 11) and control C (not shown), indicating decreased low flows for these years. Complete 1981 flow data were not available for analysis. Although the 1980 minimum flow showed no change, the number of 1980 low-flow days decreased, indicating overall increases in low flows that year. None of the B weir postlogging changes were statistically significant.

The data in Table 6 indicate that postlogging minimum flows were higher at control C relative to control E. However, pre- and postlogging comparisons of the broader range of low flows used to define low-flow days did not show this discrepancy.

DISCUSSION

Forest harvesting reduces transpiration and interception losses, leaving more water available for streamflow. This explains the increased water yields and summer low flows in H watershed and the higher valley-bottom groundwater levels. Slash burning and scarification augment changes caused by timber removal. Reduced fog interception (fog drip) by the forest canopy (Harr 1980) could explain in part the apparent decreases in water yield and summer low flows at B weir—summer fogs and low clouds being common on the outer west coast. Increased evaporation losses from the exposed, meandering stream would also occur. Yearly variations in summer low flow and water yield changes result from climatic variability, progressive increases in clear-cut area, and vegetation regrowth. The higher valley-bottom groundwater levels should have increased summer low flows, but such increases were not detected.

In other clear-cut coastal watersheds, increases in annual water yield of 20 cm (Harr et al. 1979) to 46 cm (Rothacher 1970) and minimum summer low flows of 60% to 400% (Rothacher 1970, Harr and Krygier 1972, Harr et al. 1979) have been reported. Increases of 36 cm annual yield and 78% in minimum summer low flow were found for the 90% clear-cut H watershed.

For partially clear-cut watersheds, annual water yield increases of 17 cm and 9 cm were found for 30% (Rothacher 1970) and 38% (Harr et al. 1979) clearcuts. Rothacher (1970) also noted that increases were not statistically significant until over 40% of one watershed was logged. Harr et al. (1979) reported summer low-flow increases of 65% and 44% for watersheds 30% and 50% cut over. For two 25% clear-cut drainages, Harr (1980) found decreases of 6% in annual water yields and 15% to 20% in low flows which he attributed to reduced fog drip input. Apparent decreases of 8% in annual water yield and 47% in minimum summer low flows were found for Carnation Creek at B weir, although these results must be viewed with caution pending further assessment.

Roads intercept seepage water and precipitation, creating overland flow and speeding water delivery to the stream channel. This road effect was probably the main cause of increased peak flows and decreased time-to-peak in H watershed and seems to have reduced downslope groundwater levels. Harr et al. (1979) reported increased peaks where roads occupied 5% to 12% of the drainage areas. Wetter soils in clearcuts than in forested areas, resulting from reduced evapotranspiration losses, would promote higher early fall peak flows and, possibly, midwinter peaks for smaller storms (Harr et al. 1979). While all of these processes may have occurred in the whole Carnation Creek watershed, their influence on storm hydrograph characteristics was not detected.

In other clear-cut coastal watersheds, year-round peak flow increases of 35% (Harr et al. 1979) and 50% (Harr et al. 1975) were attributed to road effects, while an 18% increase was found in one watershed where roads were not an important factor (Harr et al. 1975). Early fall peak flow increases of 40% to 200% have also been reported (Rothacher 1973, Harr 1976). After soils become recharged in the fall, forested and clear-cut areas on the coast tend to respond similarly. Little or no change in midwinter

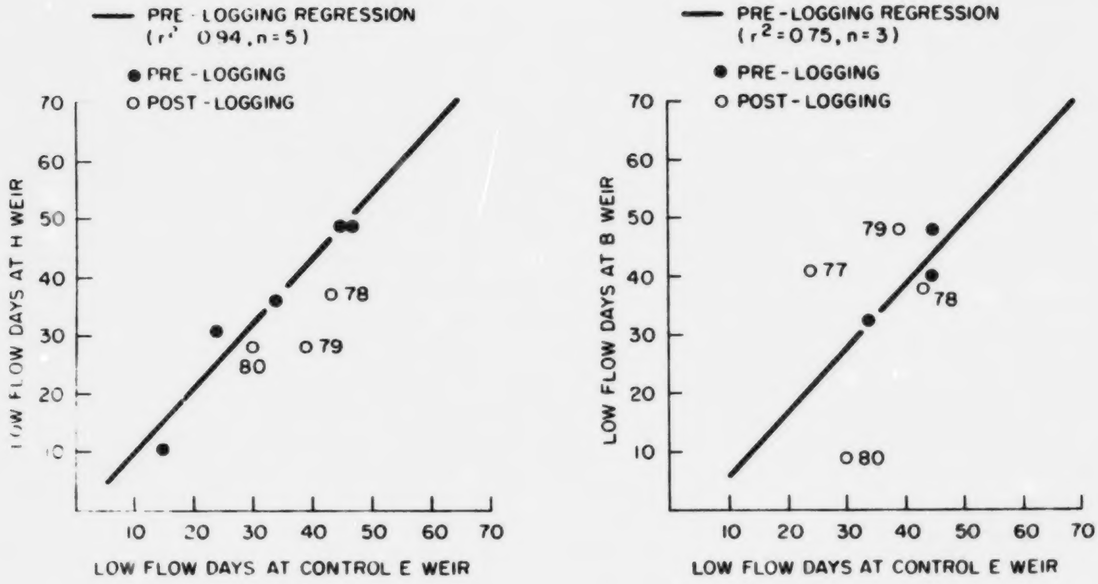

Fig. 11. Relationships between low-flow days for the logged watersheds at H and B weirs and the control at E weir.

Table 6. Changes in minimum daily summer flows (L/s) between pre- and postlogging periods at H, B, C, and E weirs.

	H	C	E		B	C	E
mean 1973-1977	0.20	4.84	5.03	mean 1972-1976	53.40	4.25	4.70
mean 1978-1979	0.37	5.24	3.36	mean 1977, 1979, 1981	40.06	6.18	5.74
change	0.17	0.40	-1.67	change	-13.34	1.93	1.04
(%)	(86)	(8)	(-33)	(%)	(-25)	(45)	(22)

or large magnitude peak flows was found in a number of other studies (Harris 1973, Rothacher 1973, Harr and McCorison 1979, Ziemer 1981). In H watershed, peak flows increased an average 20% and the first major fall peak increased 102% in one postlogging year.

For partially clear-cut watersheds, peak flow increases of 10% and 11% were found for 25% (Rothacher 1973) and 30% (Harr et al. 1979) clearcuts. Ziemer (1981) reported early fall peak increases up to 107% for a 39% selection cut drainage, while Harr (1980) found no change in another 25% clear-cut watershed. For Carnation Creek at B weir, no significant change in overall peak flows was found, although an apparent 34% decrease in one fall peak was noted. The reason for this decrease is not clear.

Mineral soil disturbance and exposure, resulting from yarding and slash burning, is the most likely cause of postlogging increases in peak slope groundwater levels. Scouring of surface soil layers could close the openings to water-conducting root channels. The slower water movement in the soil matrix would result in a higher localized groundwater table, producing temporary delayed water storage. De Vries and Chow (1978) documented this shift in flow pathway in a tensiometer plot study, while peak flow decreased 22% and time-to-peak increased in a clear-cut coastal watershed with soil disturbance on 50% of the drainage area (Cheng et al. 1975). However, any effect this soil-water slowdown had on streamflow in H watershed, with a 23% soil-disturbed area, was masked by the road effect which increased rather than decreased peaks. Apart from road effects, overland flow was not observed in H watershed. The significance of root-channel flow in coastal watersheds has also been noted by others (Nagpal and de Vries 1976, Feller and Kimmins 1979), and rapid water movement to lower soil profiles has been documented by tensiometer studies (Chamberlin 1972, Nagpal and de Vries 1976, de Vries and Chow 1978), Chamberlin (1972) reporting soil profile water flow rates of 67 to 200 cm/h.

MANAGEMENT IMPLICATIONS

Nearly complete (90%) clear-cut logging changed the hydrologic behavior of a small tributary drainage. Generally, all flow levels were higher. Aquatic fish habitat would be enhanced by increased summer low flows. In contrast, road-induced higher peak flows could increase stream channel and bank erosion and debris transport to the main channel and require larger culverts. By intercepting and diverting seepage and runoff, roads changed microhabitats, caused surface erosion and sediment transport below a culvert outfall, and could potentially cause mass soil movements. Yarding-related higher slope groundwater levels could also trigger soil mass wasting on marginally stable slopes. However, road impacts on peak flows would be reduced by slower soil-water flow rates resulting from soil disturbance.

Partial clearcutting (40%) of the main watershed caused only minor alterations to the streamflow regime of Carnation Creek. Rain-only peak flows did not change, suggesting that the threshold for detecting storm runoff changes was not reached and, possibly, that water interception and diversion effects were minimized by contour road construction. Design of road drainage structures will be aided by the peak flow frequency information, although care must be exercised in extrapolating much beyond a 14-year return period. Changes in fog interception close to the ocean probably contributed to apparent decreases in summer low flows and annual water yield. While further checks are needed to substantiate these results, the magnitudes of decreases were small and any effects were minimal. Increased valley-bottom groundwater levels could enhance side channels as summer fish-rearing habitat, but also create localized reforestation problems.

SUMMARY

Preliminary study of logging effects in the Carnation Creek watershed indicates several changes in the hydrologic regime of the 90% clear-cut H watershed, where annual water yield increased by an average 14% of annual runoff, minimum daily summer flows increased by an average 78% in the first two postlogging years, maximum slope groundwater levels decreased after road construction but increased at some locations after yarding, rain storm peak flows increased by an average 20%, while the time-to-peak storm hydrograph characteristic appears to have decreased. For the whole Carnation Creek watershed with up to 40% clear-cut, storm runoff showed little detectable change but there were some apparent decreases in annual water yield (8% of annual runoff) and minimum daily summer flows (47%), while valley-bottom groundwater levels were higher. These findings are generally within the range of results from other logging impact studies in rain-dominated coastal Oregon and California watersheds.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the enormous contribution of Department of Fisheries and Oceans personnel in streamflow and climatic data collection and reduction, particularly Charles Scrivener who has been responsible for computer processing of the data. The author is also indebted to Bob Rowswell for his years of dedicated service in collecting and processing groundwater data.

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QUESTIONS
TO E. HETHERINGTON

Question *(D. Wilford)*: I had a comment. With the increase in groundwater, you should have had more water in the back channels. Did anybody do a survey on that? Because you might have wound up by actually increasing the back-channel winter habitat. That could be part of the explanation of increased smolt production.

Comment *(unidentified (E. Packee?))*: I would like to add to the former statement that was made about the raise in the water table. In some of the logged clearcuts that we have had north there of Kennedy Lake, south of there in the Sarita and (inaudible) country and also in the Charlottes, we've had a raise in the water table sufficient that 'streams' that were not streams now support a run of salmon in the fall. They have started to move right up into these little freshet areas and are trying to spawn there wherever gravel is showing. So I would be very suspicious (suspect) that you do have an increase. What these areas formerly looked like, I don't know. But I have found salmon fry or trout fry in ponds that have been cut off that would be where a cat had wallowed through a mud hole or something like this. There was just no way that in the past they could have gotten in there and they're there now. But I see both enough water for adults to come up stream in and ponds that are very small with fish in them. Some of these are only the width of a cat's tread and 3 or 4 feet long.

LOGGING IMPACTS ON THE CONCENTRATION PATTERNS OF DISSOLVED IONS IN CARNATION CREEK, BRITISH COLUMBIA

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INTRODUCTION

An understanding of the impacts of forest practices on salmonid resources is a primary concern of western North American resource managers. Sound resource decision making requires a thorough understanding of how these resources are integrated in watershed ecosystems.

A 15-year study was initiated in 1970 to examine the effects of logging on a small west coast rain forest. Emphasis was placed on understanding watershed processes as upslope and streamside activities eventually lead to changes which can be observed in the stream. As part of the monitoring of physical parameters, chemical analyses were obtained from precipitation and stream-water samples which were collected from different subwatershed sites which had received different logging treatments. Sampling will be continued through 1985.

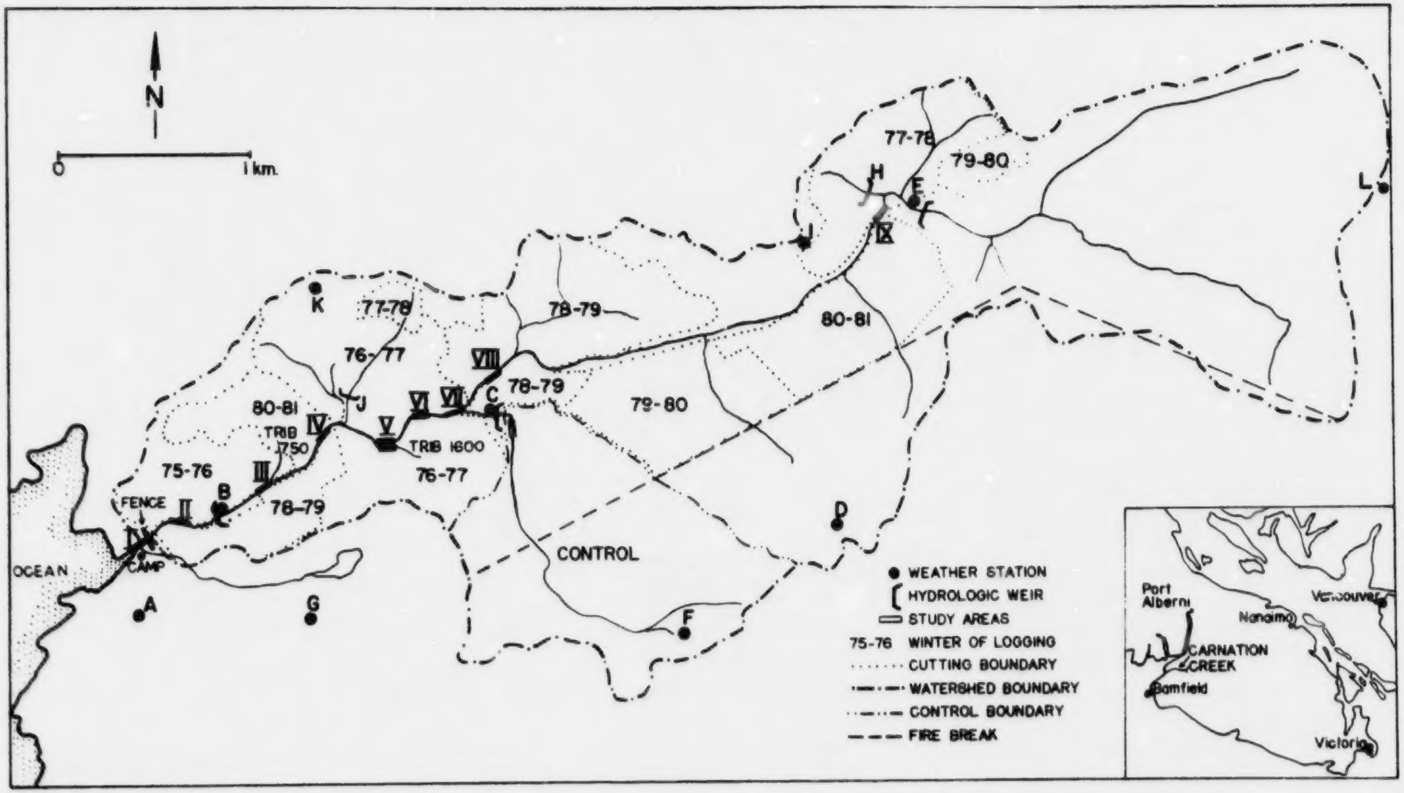
This paper describes the patterns of dissolved ion concentrations obtained from 2 stream sites during the first 10 years of the study. The patterns are related to causal elements in the environment.

STUDY AREA AND LOGGING PLANS

Carnation Creek is a small salmon and trout nursery stream which flows into Barkley Sound on the west coast of Vancouver Island, B.C. (Fig. 1). The stream is about 7.8 km long and drains an area of approximately 10 km^2. It is located within the western hemlock biogeoclimatic subzone (Krajina 1969) and is typified with coarse shallow soils, high annual precipitation (250 to 380 cm), little snowfall (less than 5%), and widely varying flows (0.017 m^3/s to 45 m^3/s). The terrain is rugged with a maximum altitude of 700 m. The stream flows mainly in a westerly direction and it is flanked by north- and south-facing slopes. Major features of the watershed have been described in more detail elsewhere (Oswald 1973, Scrivener 1975).

Anadromous fish utilize the lower 3.2 km of stream which meanders through the valley bottom (Fig. 1). This area contains chum salmon (*Oncorhynchus keta*), coho salmon (*O. kisutch*), sea-run cutthroat (*Salmo clarki*) and steelhead trout (*S. gairdneri*), coast range sculpin (*Cottus alecuticus*), and prickly sculpin (*C. asper*). Steeper tributaries drain the mainly north- and south-facing slopes. One of these tributaries, "C", contained a permanent fish population of resident cutthroat trout; another, "1600 m Creek", contained both coho and cutthroat.

Timber harvesting began in the winter of 1975-1976, with a small clearcut (23 ha) near the stream mouth. This opening, on the north side of the stream, contained only one small tributary (750 trib.) which entered the creek above B weir (Fig. 1). The area was broadcast burned in September 1976. In the winter of 1976-1977, 2 large openings—one on the north slope (61 ha) and one on the south slope (34.4 ha)—were clear-cut (Cameron Division 1979). These included tributaries "J" and "1600 m" which had been sampled for water quality. The openings were slash burned in September 1977. During 1977-1978, the remainder of J Creek (7.3 ha) and a 48.2 ha opening which included tributary watershed "H" were logged (Fig. 1). Only the yarding landings and fringes of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CONTROL
WEATHER STATION
HYDROLOGIC WEIR
STUDY AREAS
75-76 WINTER OF LOGGING
CUTTING BOUNDARY
WATERSHED BOUNDARY
CONTROL BOUNDARY
FIRE BREAK
Port Alberni
Nanaimo
Vancouver
CARNATION CREEK
Bamfield
Victoria

Fig. 1. The location of Carnation Creek and a detailed map of the watershed showing monitoring sites, stream study sections, cutting boundaries, and tributaries.

watershed "H" were slash burned. During the winters of 1978-1979, 1979-1980, and 1980-1981, another 10%, 16%, and 7%, respectively, of Carnation Creek watershed was logged. A few of the openings were slash burned, but most sites were replanted after only roadside-landing burns. Some valley-bottom sites were scarified and the debris piles were burned (Cameron Division 1979). Upon completion of the logging and forestry plan in 1981, a total of 40% of the area above B weir had been logged using a patch-clearcut method. Of the clear-cut area, 25% had been broadcast slash burned and 2.5% had been scarified. Tributary "C" and the area above "E weir" were not disturbed and have served as internal controls. Narver (1974) provides additional details about the objectives and research plans of the "Carnation Creek Experimental Watershed Project".

METHODS

Streamflow data have been obtained from 5 hydrological weirs in the watershed (Fig. 1). Continuous records were obtained from weirs B, C, E, H, and J since April 1971, May 1972, September 1971, September 1972, and November 1974, respectively. Water levels are traced by Stevens A-35 and A-72 recorders. Water Survey of Canada automated data processing techniques were used to extract and analyze the recorded data (Ozga 1974).

Water samples were collected twice monthly from the main hydrological weir at site B and from rain at site A (Fig. 1). Water samples were also collected once a month from the stream at C, E, H, and J weirs and from a bulk precipitation sampler at site A. This sampler, modelled after Likens et al. (1967), collected precipitation and dust with an open funnel. Total volume was measured on the first of each month before the water sample was obtained. More intense sampling has occurred at these sites and tributaries 1600 m and 750 m during storms. Water was collected at different water levels both during and after these storms.

Analysis for pH, alkalinity, and electrical conductivity were done in the field; in addition, samples were frozen in polyethylene bottles and transported to the chemistry laboratories at the Pacific Biological Station, Nanaimo, or the Water Quality Unit, West Vancouver, where analyses for 16 other ions were completed. Water used in the phosphate analysis was usually collected in 100 mL acid-washed glass bottles and then refrigerated. The analysis techniques used for calcium, magnesium, sodium, potassium, iron, heavy metals, chloride, sulphate, silicate, nitrate, ammonium, phosphate, and total dissolved solids determinations are outlined elsewhere (Scrivener 1975).

RESULTS AND DISCUSSION

The data presented here were obtained mainly from two sites. Station B data are used because they reflect the net changes from the various treatments and because they reflect changes which occurred in the salmonid-populated areas of the stream. Station C data are used as a fish-populated control site (Fig. 1).

Stream water was usually weakly acidic (pH 6.0 to 7.1) and conductivities ranged from 18 to 71 μmhos/cm^2. Total dissolved solids ranged from 10 to 55 mg/L, indicating a low concentration of dissolved ions.

The major cations (calcium, sodium, and magnesium) and the dominant anions (bicarbonate and silicate) showed a consistent seasonal pattern (Fig. 2; Scrivener 1975). There were pronounced concentration peaks in the summer and autumn, with lower values in winter and early spring. B weir calcium, sodium, magnesium, bicarbonate, and silicate concentrations ranged from 0.95 to 9.53 mg/L, from 0.50 to 4.63 mg/L, from 0.10 to 1.31 mg/L, from 2.80 to 15.5 mg/L, and from 0.7 to 18.1 mg/L SiO_2-Si, respectively. The lower concentrations occurred during months of high stream discharge, while higher values occurred during summer or autumn low flows.

Conductivity and Streamflow

To determine whether ion concentrations were inversely related to flows, for each year mean daily discharge (L/ha/day) on the 24 B weir sampling dates were regressed against conductivities (μmhos/cm^2). Highly significant negative relationships of the form $Y = a \log_{10} X + b$ (Y = conductivity, X = discharge) were obtained for each water year (Fig. 3). Correlation coefficients varied from -0.68 in 1976-1977 to -0.97 in 1974-1975. At Carnation Creek, the water year usually began in late September or early October during the first autumn freshets and ended during low autumn flows the following year. Data were combined from water years 1971-1972 and 1972-1973 because fewer samples were obtained

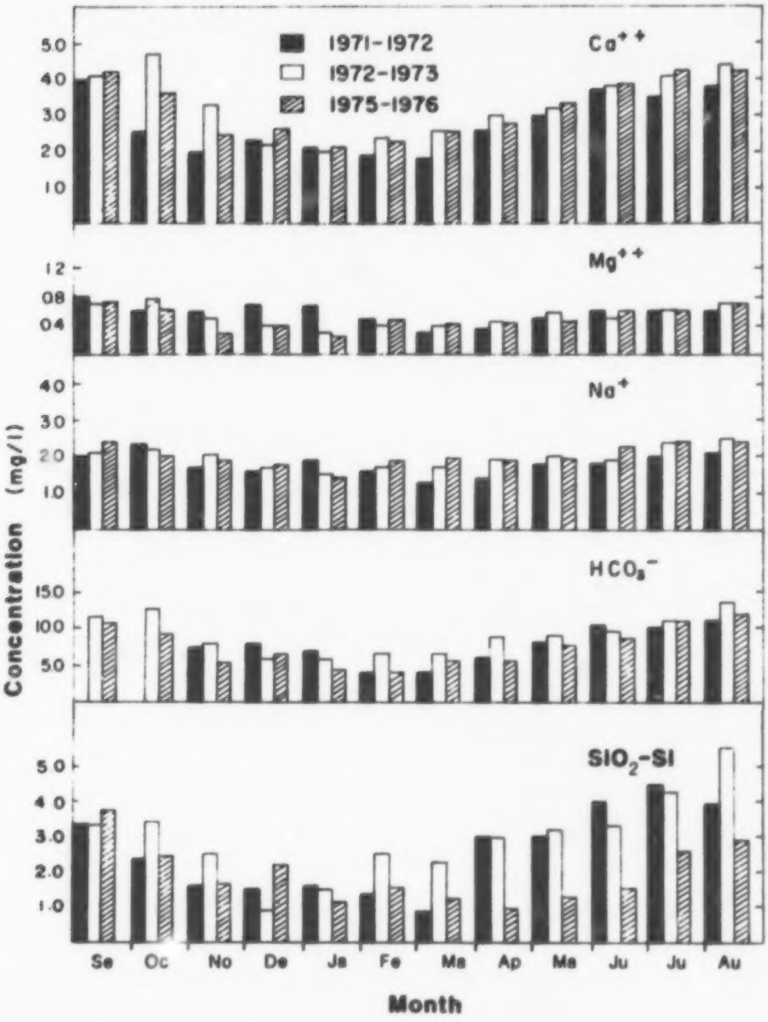

Fig. 2. Average monthly concentrations of calcium, magnesium, sodium, bicarbonate, and silicate-Si in B weir water samples during water years 1971-1972, 1972-1973, and 1975-1976. These were the first and last prelogging years.

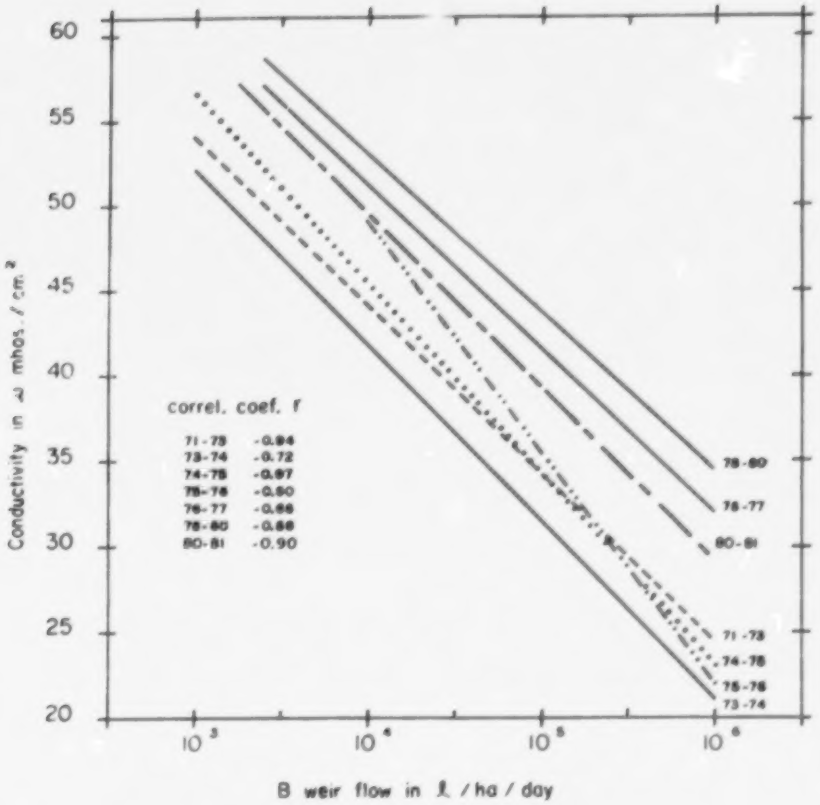

Fig. 3. Relationships between B weir conductivity and discharge for water years between 1971 and 1981. A water year usually began on October 1 and ended September 30 of the following year. 1977-1978 is not shown here because it nearly overlaps 1976-1977. Some water years are combined because little data was obtained during the years and no difference was detected between those years.

during the first year and because no difference was detected between those years (Scrivener 1975). Water years 1978-1979 and 1979-1980 were also combined for the same reasons (Fig. 3). Water year 1977-1978 was included in statistical analyses but has not been placed in the already cluttered figures (Fig. 3).

Conductivities varied inversely with the logarithm of flow during individual freshets (Table 1). During freshets in December 1972, June 1973, October 1973, February 1974, October 1974, December 1974, August 1975, March 1976, October 1976, and February 1977, conductivity was inversely related to the log of flow at the time of sampling. The slopes of these relationships were often similar, but conductivities tended to be highest per unit discharge during summer and autumn freshets (Table 1).

This indicated that previous hydrological flux could have had an effect on conductivities. To check for this phenomenon, first, mean conductivity was determined for each freshet (e.g., mean conductivity = Σ (sample conductivity x volume of flow) ÷ total freshet volume). Second, mean discharge during each freshet (L/ha/day) was determined (total freshet volume ÷ (area x time)). The predicted conductivity was then calculated by using mean freshet discharge in the appropriate water year equation of the relationship between conductivity and discharge. A measure of the previous hydrological flux was obtained from the total precipitation measured during the 60-day period prior to each freshet. Finally, the log of this precipitation total was regressed against the difference between predicted and observed conductivity for all prelogging freshets.

Table 1. Dependency of ion concentration on discharge at B weir during freshets. These values are slopes obtained when fitting data to the relationship $Y = a \log_{10} X + b$, where Y = concentration and X = discharge L/ha/day. The number of data points available and the significance of fit to the regression line are also shown (significance at 0.05 (*), 0.01 (**), or 0.001 (***)). Only conductives and alkalinities were determined on water samples from the December 1972 and June 1973 freshets.

	Freshets									
	Dec. 1972	June 1973	Oct. 1973	Feb. 1974	Oct. 1974	Dec. 1974	Aug. 1975	Mar. 1976	Oct. 1976	Feb. 1977
Conductivity	-9.9***	-6.1***	-7.3 ***	-9.6 ***	-2.8 **	-9.4***	-6.7 ***	-9.4 ***	-8.9 ***	-8.7 ***
Ca^{++}	.....	.....	-0.91***	-0.8 ***	-0.5 *	-1.1***	-0.8 ***	-0.9 ***	-0.8 ***	-0.9 ***
Mg^{++}	.....	.....	-0.11***	-0.13***	-0.03	-0.1**	-0.12***	-0.17***	-0.11**	-0.15***
Na^{+}	.....	.....	-0.22***	-0.34***	-0.12*	-0.2	-0.21***	-0.26***	-0.15**	-0.2 **
HCO_3^-	-3.3***	-1.8***	-2.8 ***	-2.6 ***	-2.3 ***	-2.7***	-3.1 ***	-2.8 ***	-3.1 ***	-2.9 ***
SiO_2	.....	.....	-14.1 ***	-9.4	-15.8 ***	-15.8***	-18.8 **	-17.2 *	-4.2 *	-5.6 *
NO_3^-	.....	.....	-1.6	-0.8 ***	+1.0	-1.9***	-0.5	-1.4 ***	+0.7	-1.3 *
$SO_4^=$	.....	.....	-0.2	+3.4 ***	+0.04	-1.5***	-1.1 *	-0.8	-0.8	-0.3
$C1^-$	.....	.....	-0.3 ***	-0.5 ***	+0.64**	-0.2	+0.12	-0.14	-0.4 *	-0.25
Minimum no. data points	23	17	22	15	20	13	21	9	20	11

A highly significant inverse relationship was obtained (F = 282.6***, Fig. 4).

Clearly, the dissolved ion content in Carnation Creek was closely related to discharge, both on an annual basis and during individual storms. This general pattern has persisted for 10 years, even though the relationships might change from one year to the next. A seasonal pattern was superimposed on these relationships because conductivity was also inversely related to the previous hydrological flux. Conductivities were higher at all discharges during summer and autumn when storms were infrequent, and they were lower in winter when freshets were common.

Annual Patterns of Individual Ions

The dissolved ions in Carnation Creek can be placed into 3 groups. Each group showed a distinct annual pattern of concentrations.

The first group consisted of the major ions such as calcium, magnesium, sodium bicarbonate, and silicate. They all demonstrated strong inverse relationships between concentration and discharge on an annual basis (Table 2) and during individual freshets (Table 1). Like conductivity, concentrations of calcium and bicarbonate were inversely related to the previous hydrological flux (Scrivener 1975). The origin of most of the ions in this group was probably more from weathering of parent bedrock or soils and less from sources outside the watershed (Scrivener 1975). Other studies indicated a similar source for these ions (Likens et al. 1977, Vitousek 1977). Conductivity served as a good illustration for this group, because its patterns were a summary of these dominant ions.

The second group consisted of nitrate, sulphate, and chloride. These ions usually have higher watershed inputs mainly in dry deposition, in precipitation, or from specific bacterial activity such as nitrification (Scrivener 1975, Likens et al. 1977, Zeman and Nyborg 1974, Vitousek 1977, Vitousek et al. 1982). Nitrate is used here as the example for this group.

Nitrate concentrations were inversely related to discharge during all but one of the water years (Table 2). The correlation coefficients were not as high as those of ions in the first group because high NO_3-N concentrations were often obtained during autumn (circled points, Fig. 5). Samples collected during autumn freshets indicated either no relationship (Table 1) or a positive relationship with flows (Fig. 6). Samples from winter freshets indicated an inverse relationship between concentration and discharge (Table 1).

Nitrate concentrations increase with flow during the first autumn freshet in October 1973, but an inverse relationship of -1.22 slope was obtained during the second freshet (F = 14.64**). Between October 12 and 14 and between October 18 and 20, a mean discharge of 79 860 and 146 087 L/ha/day transported 9.71 and 7.89 g/ha/day NO_3^-, respecttively. Clearly, nitrate losses were higher, although discharge was half as great during the first freshet. Later in February 1974, concentration was still inversely related with flow (Table 1, Fig. 5). Nitrate concentrations were higher during the second autumn freshet ($F_{2,33} = 8.3^{**}$), but they were lower during the February 1974 freshet ($F_{2,35} = 2.62$, $p = 0.08$, Fig. 6) than those which produced the 1973-1974 water year average relationship (Fig. 5).

Concentration and discharge were still directly related during the third autumn freshet on October 23, 1977 (Fig. 6). This freshet occurred after the largest broadcast slash burn of September 1977. Average nitrate losses of 28.99 g NO_3-N/ha/day were recorded during 4 freshets in autumn 1977. This was the apparent reason for the lack of an inverse relationship between nitrate concentration and discharge during 1977-1978 (Table 2). Inverse relationships were obtained at other sites (Fig. 7) and during later freshets in 1977-1978.

The patterns of dissolved nitrate in Carnation Creek were similar to that observed for conductivity, except that a phase of high concentrations were obtained during early autumn freshets. Throughout the remainder of the year, concentration was inversely related to flows. Concentrations also tended to be higher than the annual average during autumn, but they were lower later in the water year when storms were more frequent.

Sulphate and chloride patterns were similar (Tables 1 and 2). Chloride also showed a pulse of higher concentrations during the first autumn storms, but unlike nitrate which was leached from the soils (Bormann and Likens 1979), this chloride came from the forest canopy (Scrivener 1975). This observation was similar to findings at other sites in British Columbia (Feller 1977). Large quantities of chloride which accumulated in the canopy over the summer were flushed through the system during the early autumn storms (Zeman 1975, Scrivener 1975, Likens et al 1977).

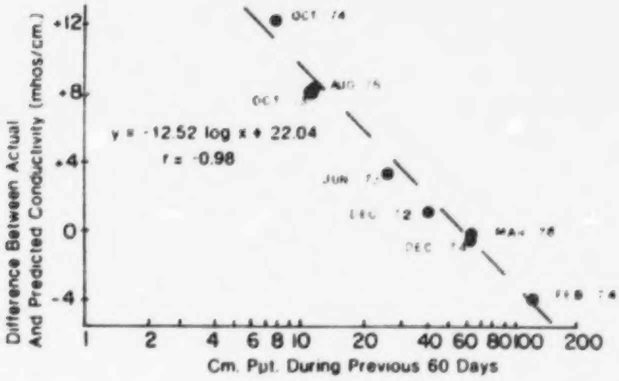

Fig. 4. The dependence of prelogging stream conductivity on the previous hydrological flux in Carnation Creek watershed.

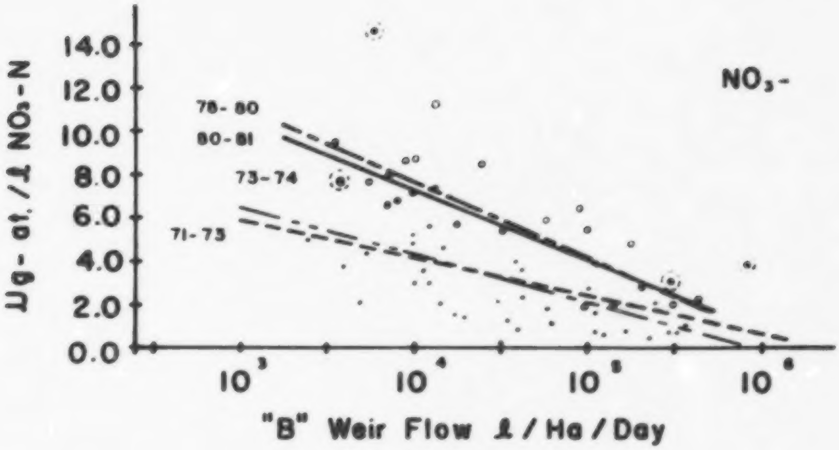

Fig. 5. Relationships between B weir nitrate-N concentration and discharge for water years 1971-1973, 1973-1974, 1978-1980, and 1980-1981. Circled points indicate higher concentrations obtained during autumn 1971, 1972, and 1978. Dots and open circles are 1971-1973 and 1978-1980 data points, respectively.

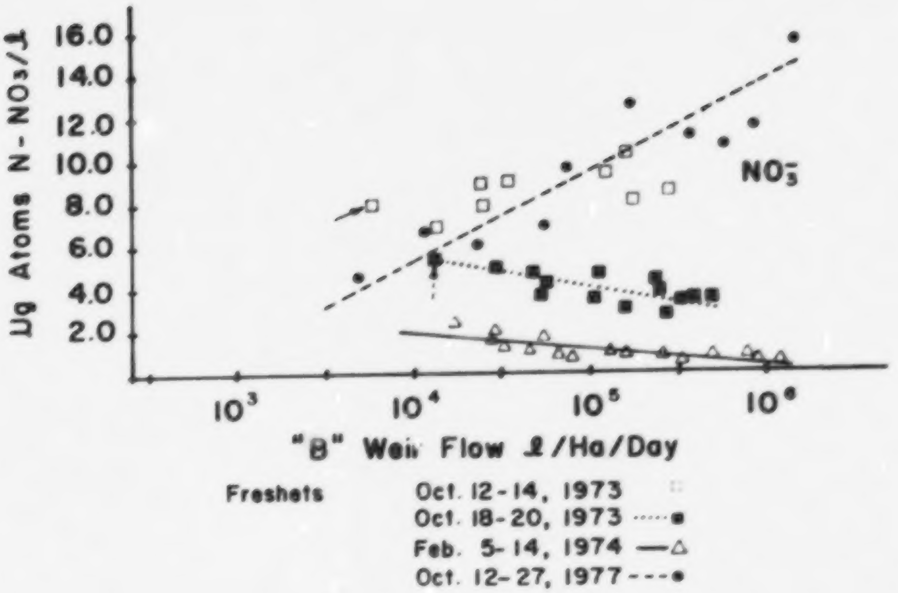

Fig. 6. Relationships obtained for nitrate-N concentration verses flow at B weir during 4 freshets in October 1973, February 1974, and October 1977. Arrows indicate concentrations at the beginning of the October 12 to 14, 1973 (solid arrow) and the October 18 to 20, 1973 (stippled arrow) freshets.

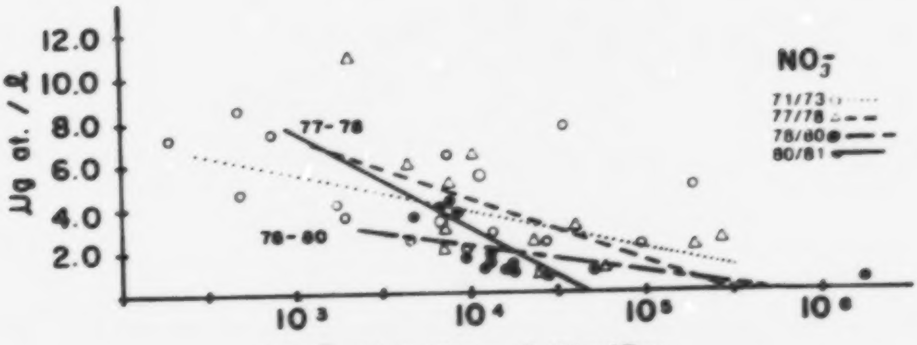

Fig. 7. Relationships obtained between C weir nitrate-N concentration and discharge during water years 1971-1973, 1977-1978, 1978-1980, and 1980-1981. Data points were not included for 1980-1981.

Table 2. Annual dependency of ion concentration on discharge at B weir. These values are slopes obtained when fitting data to the relationship Y = a $\log_{10}$ X + b, where Y = concentration and X = discharge L/ha/day. The number of points used to determine these slopes and the significance of their fit to the regression line are also shown (significance at 0.05 (*), 0.01 (**), or 0.001 (***)).

	Water Year							
	1971-1973	1973-1974	1974-1975	1975-1976	1976-1977	1977-1978	1978-1980	1980-1981
Ca^{++}	-1.01***	-1.45***	-1.28***	-1.50***	-1.16***	-0.70***	-1.84***	-2.40***
Mg^{++}	-0.15***	-0.19***	-0.16***	-0.21***	-0.15***	-0.16***	-0.23***	-0.35***
Na^+	-0.36***	-0.70***	-0.28***	-0.35***	-0.28***	-0.03	-0.37**	-0.70**
K^+	-0.03	-0.04**	-0.03**	-0.03**	-0.01	-0.04	-0.01	-0.00
HCO_3^-	-3.4 ***	-3.6 ***	-3.7 ***	-4.3 ***	-3.4 ***	-3.2 ***	-3.6 ***	-4.8 ***
SiO_2	-20.0 ***	-16.0 **	-17.4 **	-13.0 **	-10.3 ***	-10.7 *	-20.6 **	-34.3 ***
NO_3^-	-1.8 **	-2.2 ***	-2.2 ***	-1.5 **	-1.3 **	-0.6	-2.4 ***	-3.1 ***
$SO_4^=$	-0.7 *	-1.1 *	-1.2 ***	-1.5 **	-0.9 ***	-0.5	-0.8 *	-0.9 ***
Cl^-	-0.55**	-0.22*	-0.22	0.11	-0.09	0.05	-0.01	0.03
TDS	-3.4 *	-9.2 ***	-6.9 ***	-6.7 ***	-0.7	-1.9	0.2	-0.7
Minimum no. of data points	42	24	25	24	23	24	25	24

Pulses of high sulphate concentrations did not necessarily occur during the first autumn freshet, but also occurred during freshets later in the winter (Table 1). This appeared to be associated with large precipitation inputs (Scrivener 1975).

The third group consisted of ions such as phosphate and ammonium. Concentrations varied from < 0.95 to 28.5 μg/L PO_4-P and from < 1.8 to 61.2 μg/L NH_4-N. Phosphate concentrations were usually in the lower end of the range and they showed no apparent relationship with discharge (Fig. 8). High concentrations within the range have been obtained during freshets in October, February, March, and June—suggesting also that no seasonal pattern existed.

Logging Impacts

In order to determine logging-related impacts, data from pre- and during-logging years were compared for both site B and control site C. Analysis of variance was used to test for significant differences in slopes or intercepts between water year regression lines.

The dominant ions, as represented by conductivity, increased at B weir after 1975-1976. A significant difference among the 8 years was obtained for the conductivity vs. discharge regressions (Fig. 3, $F_{14,201} = 12.5^{***}$). This difference among years was mainly due to the greater Y-intercepts obtained in during-logging years and the steeper slope obtained from 1975-1976 data (Fig. 3). The slopes among the water years were significantly different ($F_{7,193} = 2.15^{*}$) only before data from 1975-1976 was excluded from the analysis ($F_{6,173} = 1.57$ N.S.). 1975-1976 was an extremely wet year with frequent freshets (Hetherington 1982) which could explain the low conductivities during high flows and therefore steeper slope. Minimum flows were also much higher during this year. Conductivities were also significantly greater during 1976-1977, 1977-1978, 1978-1980, and 1980-1981 than during any prelogging water year (minimum $F_{2,69} = 20.23^{***}$). The highest conductivities were obtained for 1976-1977 and 1978-1980 which were also very dry years (Hetherington 1982). Dry conditions probably contributed to the high values during these years, because conductivity was dependent on hydrological flux (Fig. 4). During 1980-1981, precipitation (310 cm/yr) and discharge (296 cm/yr) regimes were similar to those of prelogging years (Hetherington 1982).

Conductivity at C weir was inversely related to discharge during all water years (Fig. 9). Conductivities were significantly different among the 8 water years ($F_{14,105} = 4.5^{***}$). The slopes alone of the regression lines were also significantly different among year ($F_{7,98} = 3.24^{**}$), but no difference among years was obtained when data from the extremely wet year, 1975-1976, and the extremely dry year, 1978-1980, were excluded ($F_{5,80} = 1.88$ N.S.). The regression lines were also different among years because Y-intercepts tended to be higher (mean = 167.7) during prelogging than in during-logging years (mean = 147.8). The Mann-Whitney J test probability that this was due to chance alone was 0.10 ($\mu = 3$). These results suggested that the extremes in hydrological flux observed during 1975-1976, 1976-1977, and 1978-1980 were the main contributor to differences between years. Conductivities were lower during 1980-1981 than those of prelogging (Fig. 9), and they were significantly lower than those of 1975-1976, a similarly wet year ($F_{2,22} = 3.4^{*}$).

Apparently, two phenomena influenced the annual relationship between conductivity and discharge and they both contributed to the higher conductivities which have been obtained at B weir since 1975-1976. First, logging and slash burning activities produced higher conductivities. This was most apparent during 1980-1981 when conductivity was significantly greater than during any prelogging year at B weir, but not at C weir. Second, conductivities were greater during years of low hydrological flux. This was apparent during 1976-1977 and 1978-1980 when values tended to be greater than during prelogging years at both sites.

Nitrate concentrations have also changed since logging and burning were begun in the watershed. At B weir, the annual patterns in nitrate-N concentration were different between the 8 water years (Table 2, $F_{14,200} = 8.5^{***}$), but no difference was obtained between 1971-1973 and 1973-1974 ($F_{2,55} = 0.30$ N.S.) and between 1978-1980 and 1980-1981 (Fig. 5, $F_{2,42} = 0.39$ N.S.). A comparison of these pre- and during-logging years indicated that the linear-log relationships were significantly different (F_{2}, 101 = 15.85***) because nitrate -N concentrations were greater during 1978-1980 and 1980-1981. The pattern of nitrate -N concentrations at C weir were also significantly different during these same years ($F_{2,58} = 5.58^{**}$), but they were lower during 1978-1980 and 1980-1981 (Fig. 7, Table 2). Clearly, nitrate concentrations have increased at B weir but they have either decreased or remained unchanged at C weir since the logging and forestry plan was

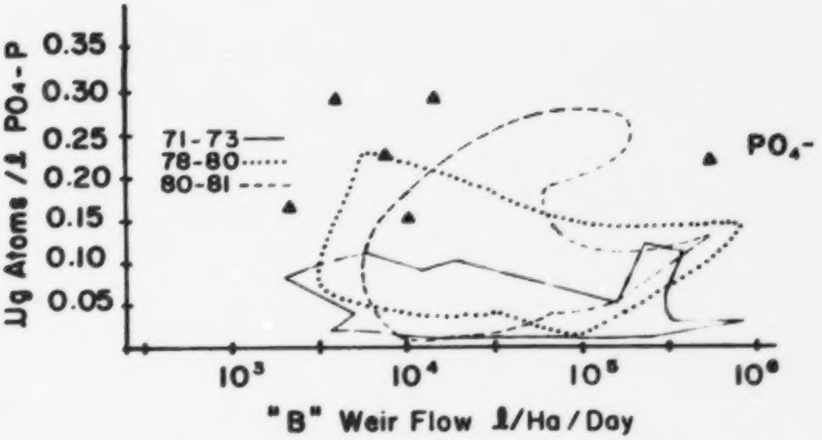

Fig. 8. Plots of ranges obtained for phosphate-P concentration and discharge at B weir during water years 1971-1973, 1978-1980, 1980-1981. Triangles identify values obtained after slash burning in autumn 1977.

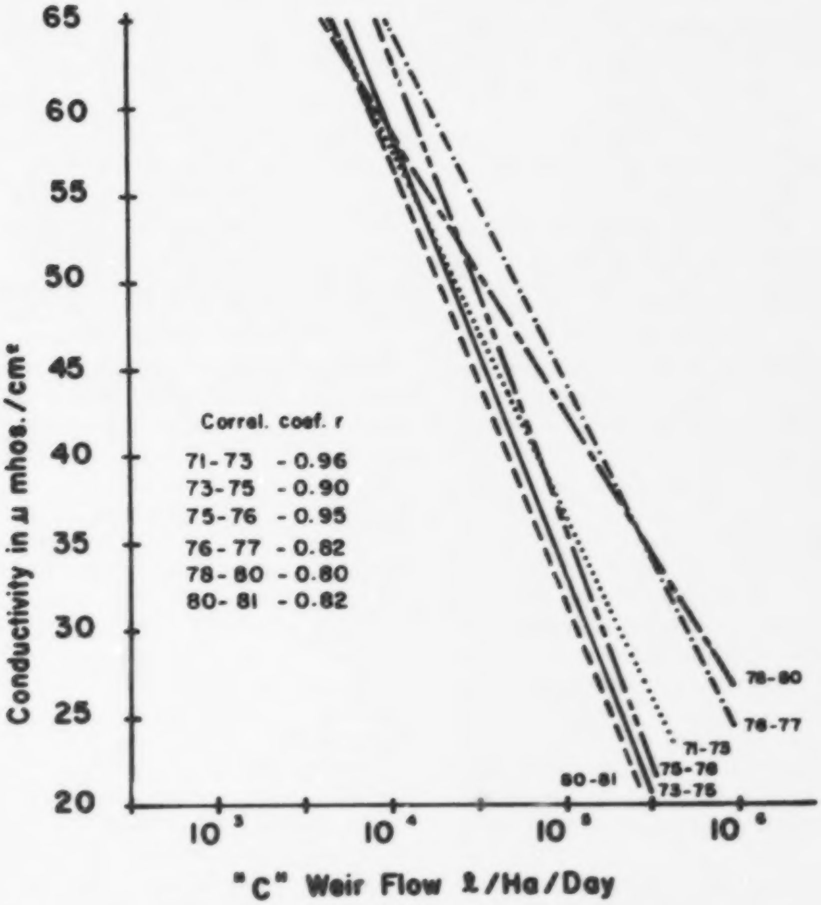

Fig. 9. Plots obtained for the water year relationships between conductivity and discharge at C weir, the control area in Carnation Creek watershed. Water years 1973-1974 and 1974-1975 were combined because the lines were almost overlapping.

initiated. Similar increases in stream nitrates have been observed after logging and slash burning in other basins (Brown et al. 1973, Bormann and Likens 1979, Vitousek et al. 1982).

Ions from the third group such as phosphate did not appear to increase significantly after 1975-1976. The maximum values increased from 8.6 to 28.5 μg/L PO_4-P during-logging years, but most concentrations were still near 0.95 μg/L, the minimum detectable limit of the chemical analysis technique (Fig. 8, Scrivener 1975). High values were obtained for 2 months after broadcast burning in September 1977 (Fig. 8); but if these values are excluded, annual median values have remained between 2.8 and 3.8 μg/L PO_4-P. A similar scatter diagram of phosphate concentrations was obtained from plots of C weir data (Fig. 10). The largest phosphate concentration recorded to date was obtained in 1971 from this control site (Fig. 9). Dissolved phosphorus concentrations also remained unchanged during the Alsea study (Brown et al. 1973).

CONCEPT OF VARIABLE SOURCE AREA AND AN EXPLANATION OF CARNATION CREEK FINDINGS

The relationships between ionic concentration and discharge and the phenomenon of ionic flushing in autumn which were observed in Carnation Creek can be explained by present concepts of nutrient cycling (Feller 1977, Bormann and Likens 1979, Gorham et al. 1979, Whittaker et al. 1979) and of variable source area in relation to runoff (Hewlett and Hibbert 1967, Nutter 1969). First, dissolved ions in the stream are leached from the vegetation and soils as precipitation passes through the watershed to the stream (Bormann and Likens 1979). Leaching is a process by which dissolved anions (negatively charged ions such as HCO_3^-, $C1^-$) which are not retained by the watershed (Feller 1977) extract cations (positively charge ions, Ca++, Mg++) from the system as water moves to the stream. This process maintains the electroneutrality of the solution (Feller 1977). Therefore, the quantity of dissolved stream ions (which is measured by conductivity) is dependent on the anions transported and the availability of leachable cations.

Large quantities of elements are stored on and in the vegetation in organic detritus, soils, and bedrock of the watershed (Bormann and Likens 1979). Ions such as chloride buildup on the vegetation between storms by processes of impaction or dry fallout (Zeman 1975, Scrivener 1975). Processes such as weathering of soils and bedrock, respiration of roots and bacteria in the soil, and decomposition of organic detritus release elements as soluble ions which can be leached. The rates of these processes are greater at higher summer temperatures (Likens et al. 1977); therefore, more material is available to be leached during the summer and after a long dry period. This explains the seasonal pattern of stream ions and their dependence on the previous hydrological flux.

This system is made more complex by processes such as nitrogen fixation where bacteria convert atmospheric nitrogen to soluble nitrate (Vitousek et al. 1982). Soluble phosphorus is rapidly assimilated by vegetation both terrestrial and aquatic so it is not very leachable (Feller 1977, Shortreed and Stockner 1982). This explains the low concentration and the lack of seasonal pattern for dissolved phosphorus in Carnation Creek.

The inverse relationship between discharge and concentration can be explained by the concept of variable source area which describes processes of water movement through the soils to the stream. During a storm, precipitation infiltrates unsaturated soil and percolates down through it to a nonporous layer (bedrock) and then downslope at flux rates that are proportional to the water content of the soil (Hewlett and Hibbert 1967). Associated with downslope drainage is a slope moisture gradient from channel to ridge (Nutter 1969). Proceeding upslope, each unit of precipitation contributes more to temporary storage and less to storm or direct runoff. Direct runoff is "the amount of flow resulting directly from a rainfall or snow-melt event" (Hewlett and Hibbert 1967). Of the part contributed to direct runoff, a fraction will be some new rain and the other fraction will be "translatory flow" or flow produced by displacement (Hewlett and Hibbert 1967). This is direct runoff from water already stored in the soil mantle before rainfall began. Since this water has associated with soil longer than new rain water, it has leached more minerals from the soil. Translatory flow increases rapidly when the water-holding capacity or "field capacity" of the soil is reached because of a thickening of the water films surrounding soil particles (Hewlett and Hibbert 1967). As more displaced soil water reaches the nonporous layer, a zone of saturation develops. Even the large interstices in soil now fill and water moves rapidly downslope in the soil microchannels

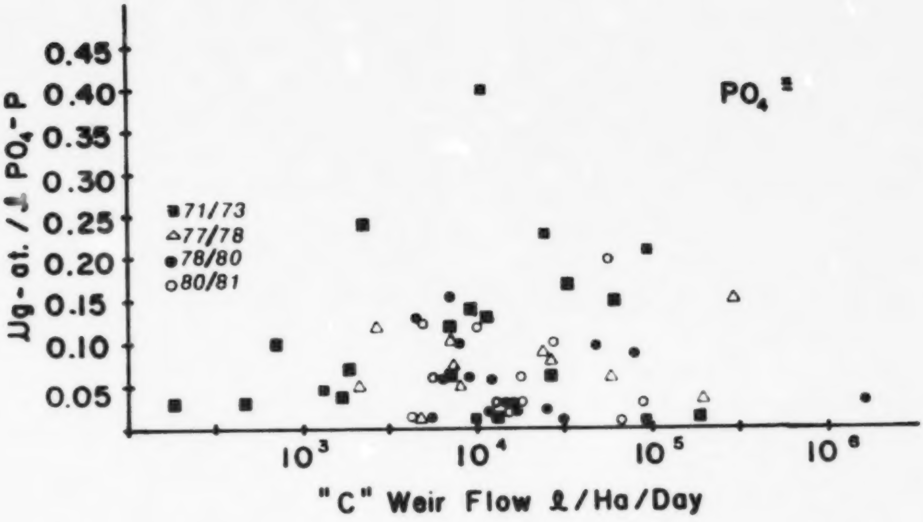

Fig. 10. Scatter plots obtained from C weir phosphate-P concentrations and discharges during water years 1971-1973, 1977-1978, 1978-1980, and 1980-1981.

associated with tree root systems. At the base of the slopes, the whole soil profile is saturated from continual downslope drainage and water surfaces in a perennial channel.

During storms, the source area of runoff expands upslope out from perennial channels as the zone of saturation expands. The rate at which the source area grows is dependent in part on the storage capacities of the soils, on their depth, on their antecedent storage condition, and on the precipitation intensity (Nutter 1969). As the source area expands, channels are also expanding in length and the capacity of slope soils to transmit subsurface water is exceeded at draws or breaks in the slope where the soil is saturated to the surface and water emerges as ephemeral channels. Extension of the channel network promotes more rapid response of their adjacent areas, because the distance travelled to a channel by displaced soil water is shortened and the channelization hastens delivery of storm flow downstream (Nutter 1969). Few ions are now leached by this transitory water because of its shorter association with the soil. During large storms, the channel network expands upwards into subsurface macrochannels formed from old decayed roots (Hetherington 1982). Under these conditions, precipitation can be intercepted by the canopy and channelized into stem and macrochannel flow with little association with the soil. Therefore, more and more of the stream water consists of transitory water with few dissolved minerals. The source area of runoff and the channel network begin shrinking again when the precipitation stops. This produces longer association of water and soil and again permits more time for leaching.

Management Implications

Partial clear-cutting of the main watershed caused significant increases in dissolved ions in the stream and therefore losses to the forest ecosystem. Little can be said about the consequences of this impact on the terrestrial ecosystem at this time, except that more nutrients are now available for present vegetation. Later in the forest succession when nutrient demands are greater (30 to 40 years; Borman and Likens 1979, Gorham et al. 1979), will there still be an adequate supply to maintain a 60-year harvesting rotation as planned?

For sulphur, nitrogen, magnesium, sodium, calcium, and potassium, meteorologic input supplies about 66, 26, 6, 5, 4, and 1%, respectively, of the annual uptake by the forest (Likens et al. 1977). Large increases in dissolved anions such as NO_3^- and $SO_4^=$ cause increased leaching of cations such as Ca++, NA+, Mg++, and K+. This maintains a neutrally charged solution (Feller 1977). Since atmospheric inputs can provide only a small fraction of the cations required by the new forest, losses of these minerals can have serious consequences to regeneration if soil decomposition and weathering of bedrock does not replace these losses.

Impacts of increased dissolved ions on the stream ecosystem did not appear substantial. The large flux of nutrients occurred during autumn freshets and after the spring and summer period of epiphyton growth. In an oligotrophic system such as Carnation Creek, opening of the stream to increased energy inputs has increased stream metabolism (J. Culp, Department of Biology, University of Calgary, pers. comm.), but since clear-cutting had little effect on dissolved phosphorus in the stream, neither beneficial nor detrimental effects on the algal community are expected. Phosphorus appeared to be the nutrient limiting algal growth in Carnation Creek (Stockner and Shortreed 1982).

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The interest, support, and constructive criticisms provided by working group members of the Carnation Creek project and the project coordinator, Dr. G. Hartman, are gratefully acknowledged. The manuscript was reviewed by Dr. G. Hartman and Dr. B. Holtby. Most of the chemical analyses were done by Messrs. K. Stephens, T. Nason, J. Davidson, and members of the E.P.S. Laboratory. Assisting in field work and data analysis were Messrs. P. Neaves, B. Andersen, and R. Leahy.

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QUESTIONS
TO J.C. SCRIVENER

Comment *(unidentified)*: Regarding your work on water chemistry, I think we have a great opportunity here, due to the fact that you looked at the condensation of fog on the trees. You have tried to measure that and you also collected chemical concentration information. That could be valuable data to help us understand ion movement into watersheds.

Answer *(C. Scrivener)*: We have a fair amount of information about what is happening on the canopy. I was mentioning things like chloride showing the pulsing effect. Much of the chloride, or probably most of it, is coming from outside and you certainly get large chloride buildup on the canopy through the summer. This flushes through the system very rapidly in the first fall storms.

Comment *(unidentified)*: I was specifically referring to the importance of trying to separate out the contribution that comes in from precipitation directly, as raindrops, and the material that comes in associated with condensation from fog. There's some suggestion that in these coastal systems this can be a very important contributor of moisture and may also be important for the chemical budget as well.

Question *(unidentified)*: I'd like to ask why you would expect different chemical concentrations in the fog? Is fog not just low cloud? Why would it be different than precipitation? I realize that by limiting what is classed as precipitation and ignoring fog condensation you don't get an accurate estimate of how much is coming in. Is there any reason to expect the concentrations to be different?

Answer *(unidentified)*: Perhaps not, but it would certainly be interesting to sort this out.

Comment *(C. Scrivener)*: We do collect bulk precipitation in a constantly open container to measure dry-fall. Whatever would be contributed by fog would come in in that portion.

Comment *(unidentified)*: There's little doubt that the chemical composition of the dry fallout can be quite different than the wet fallout. I'm not sure whether the fog condensation would be different but I think we certainly have a great opportunity to investigate.

A PRELIMINARY ANALYSIS OF LOGGING-RELATED TEMPERATURE CHANGES IN CARNATION CREEK, BRITISH COLUMBIA

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INTRODUCTION

The harvest of trees often alters temperature regimes of creeks under the forest canopy, but there are few studies in the published literature, relevant to the coastal basins of British Columbia, that document changes in temperature after the trees have been cut and few studies that attempt to predict such changes before cutting begins. The lack of pertinent information forces planners to guess at the probable effects of logging on fisheries resources and to form their own opinions regarding the best strategy for removing trees while protecting the capacity of the stream to produce fish.

Streamside shade protects small streams from excessive warming when the rest of the basin is clear-cut. In a West Virginia study, streamside shade extended along the entire length of the permanent stream channel; but despite the shade, some warming still occurred. However, the increase in temperature was apparently too small to be of consequence to fish (Aubertin and Patric 1974). In an Oregon study, clear-cutting, by removing all shade, caused an enormous increase in maximum temperature in one stream; but patch-cutting, by preserving some shade, caused stream temperature to remain stable (Hansmann and Phinney 1973). The amount of warming is apparently proportional to the area of the stream exposed to sunlight (Brown 1969, 1970, 1971; Corbett et al. 1978). Therefore, the question of how much shade is actually required along the stream bank is an important one for the managers of forests and fish stocks to answer objectively. Trees left to provide shade where none is needed represent lost capacity of the forest to produce lumber; and trees cut down where shade is needed reduce the capacity of the stream to produce fish.

Although streamside shade is an important moderator of water temperature, it is not the only factor. Evidence for this comes from other studies that depict air temperature as one of the major determinants of water temperature (Cluis 1972, Kothandaraman and Evans 1972). These studies examine the seasonal cyclic variations and daily stochastic variations of air and water temperature, but the models describing these relationships are not necessarily able to predict changes in water temperature caused by timber harvest. However, the existence of these models does raise the question of the relative importance of air temperature and sunlight on water temperature of streams.

Other models, specifically designed for predicting the temperature changes in streams caused by timber harvest (Brown 1969, Ringler and Hall 1975, Vugts 1974), appear initially to be suited ideally for use in coastal basins of British Columbia. But the models developed by Brown and Ringler and Hall were based on very small streams and may be less applicable to streams that are larger. It seems, too, that most of the models are based on rates of energy flux and energy balance—information that may not be readily available to planners in British Columbia.

Most studies pertaining to the effects of timber harvest report the size of temperature increases caused by this activity. But very few even mention diurnal range, and apparently there are none, with the possible exception of Brown (1969), that attempt to predict this range. The lack of emphasis on diurnal range is understandable because changes in daily maxima are more pertinent to the survival of fish, but with regard to metabolic activity of other biota in the stream, diurnal range may be an important variable.

The study reported in this paper examines the changes in water temperature that occur in a forested coastal basin when the timber was harvested.

METHODS

The Carnation Creek Study area is thoroughly described elsewhere (Anon. 1974). Methods for the measurement of air and water temperatures and flow are outlined in Hartman et al. (1982). Solar radiation was recorded continuously with a Belfort pyrheliometer situated at weather station "A" (Fig. 1).

RESULTS

Diel Range

Prior to logging, diel ranges (maximum-minimum daily temperature) during the summer (June to August) were on average small, varying from 0.42°C in the smallest tributary "H" to 1.1°C in the main stream "B". These values are comparable to those observed in an Oregon watershed study (Moring 1975).

After complete clear-cutting, the diel ranges in two small tributaries, "H" and "J", increased considerably (Figs. 2 and 3). The mean diel ranges increased further in "J" tributary after slash burning (Fig. 3). Although variable, mean diel ranges in control tributary "E" showed no increase over time (Fig. 4). Diel ranges in the main stream "B" showed no detectable changes up to the summer of 1978 when 10% of the basin had been logged (Fig. 5). The important features of stream morphometry that affect temperature fluctuations are the surface area/volume ratio (SA/VOL) and the gradient (Brown 1971). Streams with a large SA/VOL have a large surface area over which heat transfer can occur and low thermal inertias and therefore should have relatively large diel temperature fluctuations. Water residency time should decrease with increasing gradient, reducing the amount of time available for heat exchange and consequently moderating temperature fluctuations. SA/VOL ratios are significantly correlated with mean diel temperature ranges prior to logging (Fig. 6a, Pearson's $r = -.965$, $p < 0.01$).

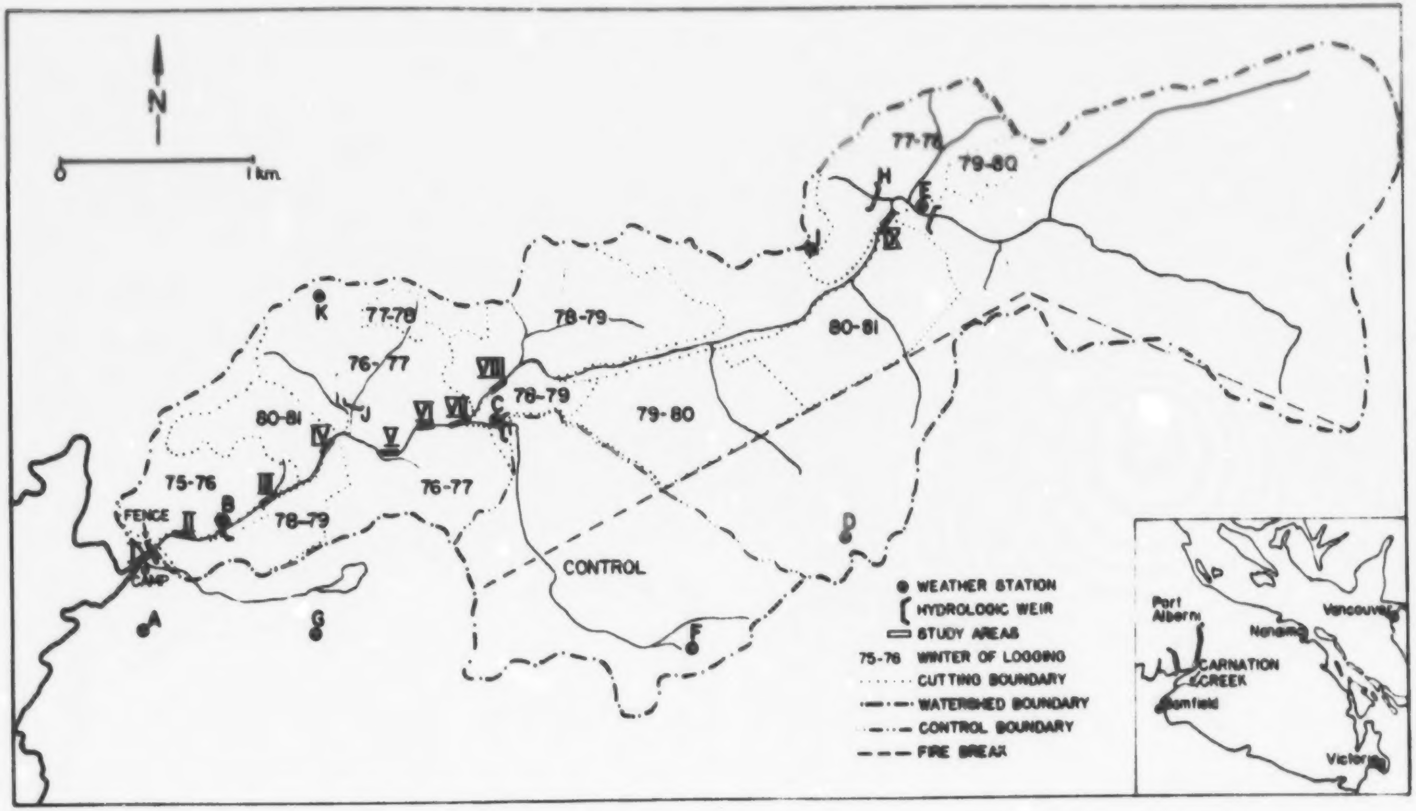
During the prelogging period, diel temperature range could also be predicted from the basin area of each tributary (Fig. 6b). This relationship is accounted for by the significant correlation between basin area and the SA/VOL ratio of each tributary (Pearson's $r = .917$, $p < 0.05$). Increased temperature fluctuations after logging are probably due to increased amounts of solar radiation reaching the stream surface, resulting in increased stream warming during the day (Brown 1970, 1971).

Prediction of Average Stream Temperature

In order to assess the impacts of logging on average stream temperature, a model relating average stream temperature to average air temperature, daily solar radiation, and total daily flow was developed. All data used in this model were 30-day averages for the prelogging period January 1, 1973 to December 31, 1974. Water temperatures and flow were measured at B-weir; air temperatures and radiant solar energy were measured at the Station A weather station (Fig. 1).

All correlations between the four variables are highly significant (Table 1) and reflect the seasonal weather patterns of the western rain forest region. Water temperatures are highest during the summer when air temperatures and solar radiation are at their yearly maxima and while flows are at their yearly low (Fig. 7). Winters are characterized by low air and water temperatures, low levels of solar radiation, and high flows.

In order to predict the water temperature that would be observed at any given combination of air temperature, solar radiation, and flow, a multiple linear regression model was employed (Table 2). The signs of the regression coefficients for air temperature and flow indicate that high water temperatures are associated with high air temperatures and low flows. This is a reflection of general climatic patterns in the region, as were the signs of the correlation coefficients. The negative sign for the solar radiation coefficient indicates that, all else constant, water temperature declines with increasing solar radiation. This possibility reflects a tendency for bright clear days to be followed by cool nights which results in lower mean water temperatures than would otherwise be expected. Note that the sign in the regression model is opposite to that of the simple correlation.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CUTTING BOUNDARY
WATERSHED BOUNDARY
CONTROL BOUNDARY
FIRE BREAK
Port Alberni
Nanaimo
Vancouver
CARNATION CREEK
Bamfield
Victoria

Fig. 1. The Carnation Creek Study Area. Water temperature data were collected at B-weir on the mainstem of the creek and at C, E, H, and J weirs on tributaries. Discharge data used in this study were collected at B-weir. Air temperatures and incident solar radiation data were collected at weather station A.

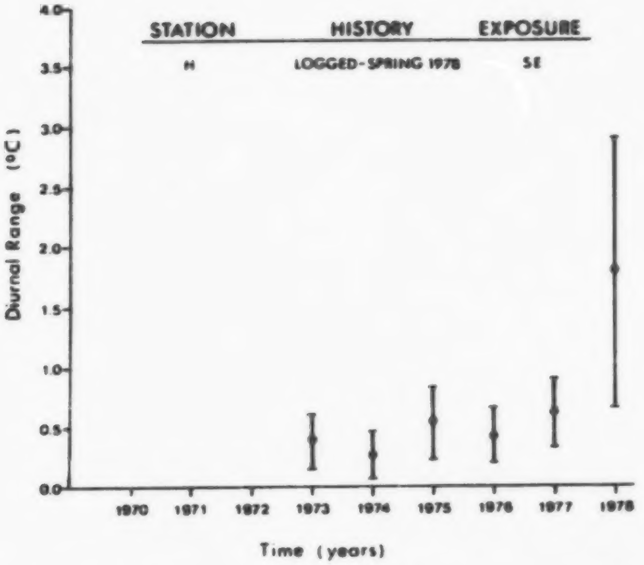

Fig. 2. Diel temperature range in "H" tributary for the summer months June, July, and August. The solid circle is the mean diel range for this period. The vertical bars show the minimum and maximum ranges observed. The logging history and the general exposure of the logged area are shown.

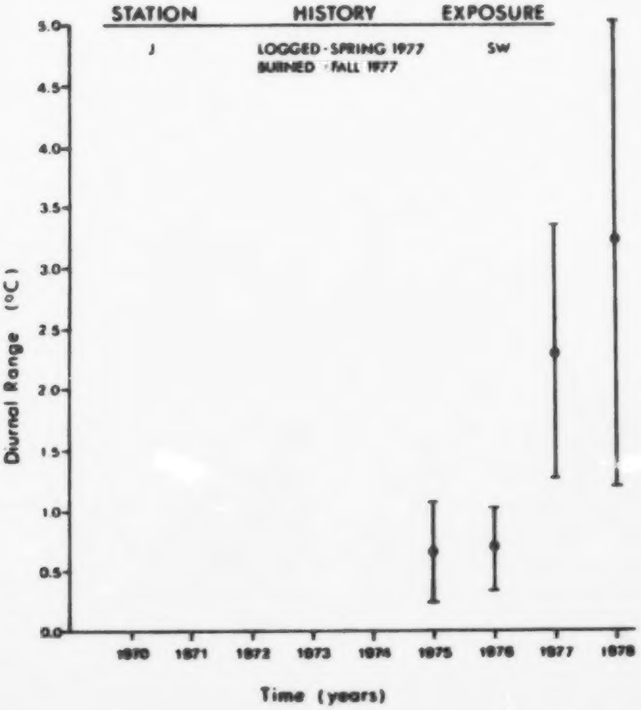

Fig. 3. Diel temperature range in "J" tributary for the summer months June, July, and August.

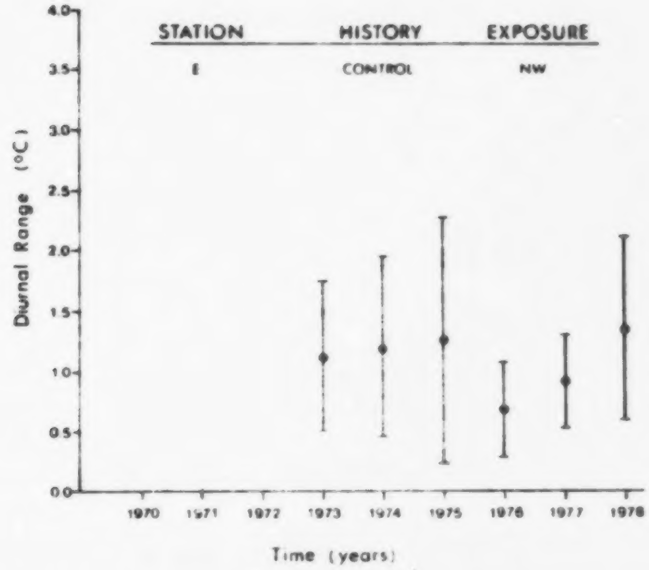

Fig. 4. Diel temperature range in the unlogged "E" tributary for the summer months June, July, and August.

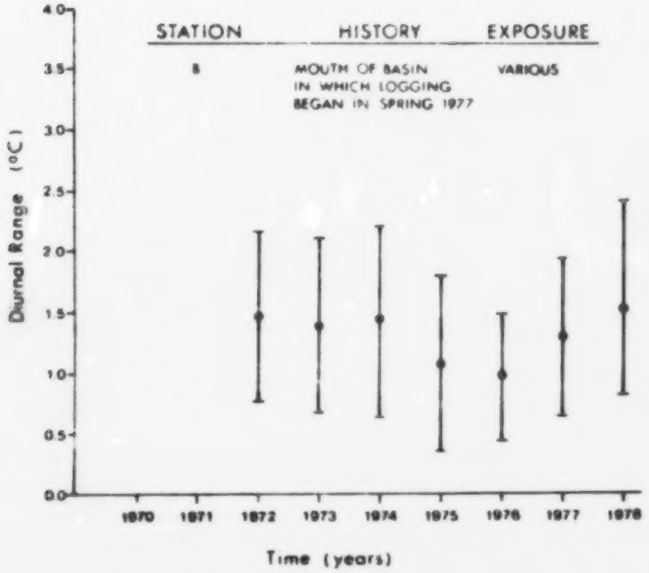

Fig. 5. Diel temperature range in Carnation Creek mainstem for the summer months June, July, and August.

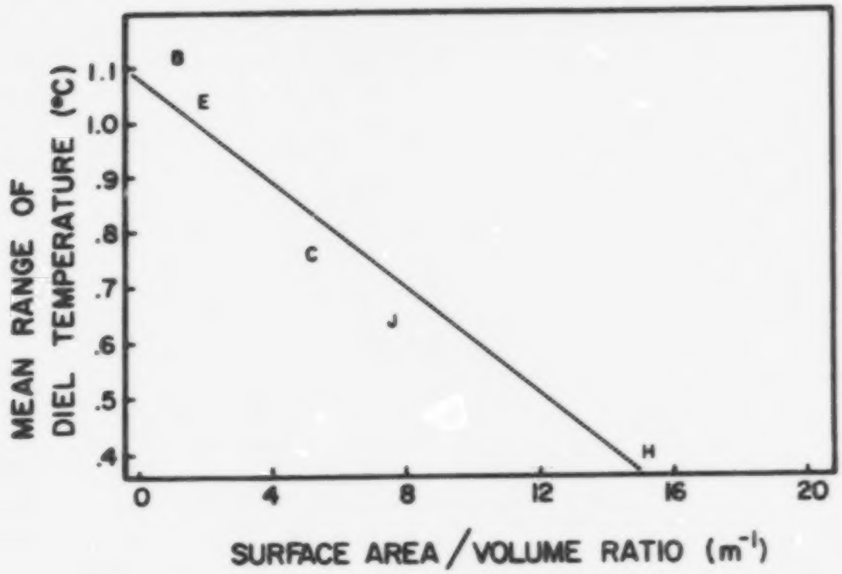

Fig. 6a. Mean diel temperature ranges as a function of surface area/volume ratios for Carnation Creek mainstem "B" and four tributaries—"E", "C", "J", and "H". Diel temperature ranges were averaged over the summer months June, July, and August only for prelogging years (see Figs. 2 to 5).

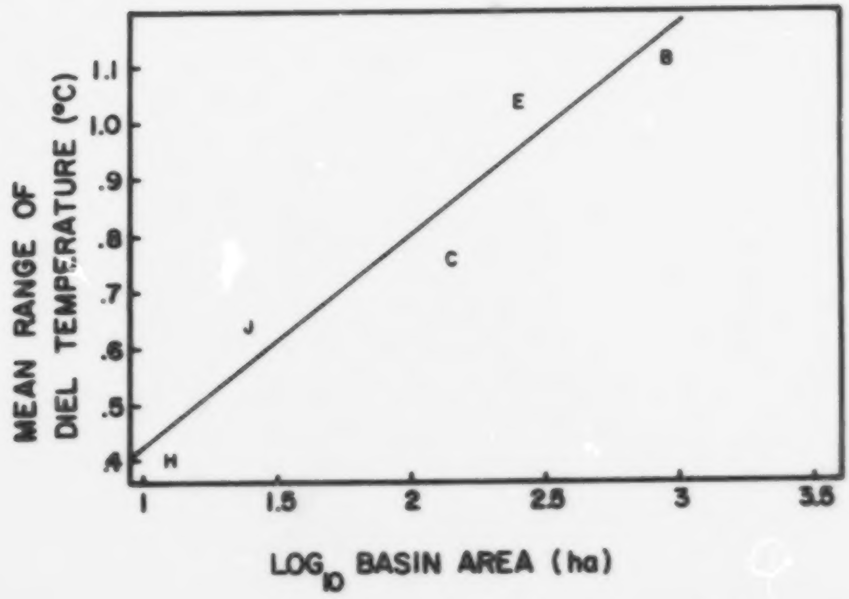

Fig. 6b. Mean diel temperature ranges as a function of the logarithm of basin area. The surface area/volume ratio is significantly correlated with basin area.

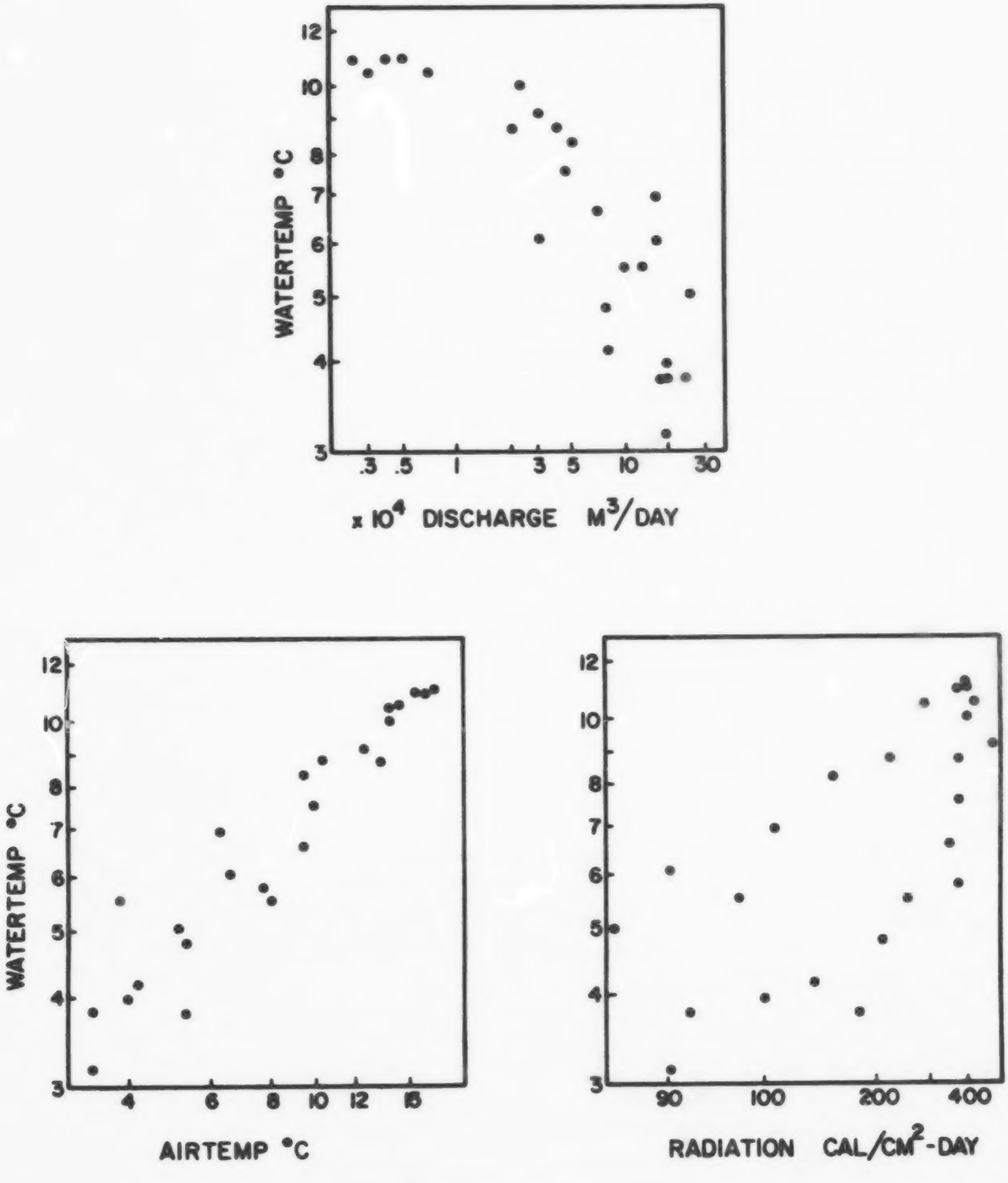

Fig. 7. Water temperature at B-weir as a function of:

(a) Daily discharge at B-weir.
(b) Air temperature.
(c) Incident solar radiation at weather station A.

Data shown are 30-day averages for January 1, 1973 to October 31, 1974. There had been no logging activity in the Carnation Creek basin prior to this period.

Table 1. Correlations between average water temperature, average air temperature, daily solar radiation, and daily stream discharge. Data used in the calculations are 30-day averages for the period January 1, 1973 to December 31, 1975. The statistical test, Pearson product moment, indicates significant correlations ($\alpha = 0.01$; 22 d.f.) when $p \geqslant 0.515$.

Variable	Water Temperature (°C)	Air Temperature (°C)	Solar Radiation
$\log_{10}$ water temperature +1.0 (°C)	1.000		
$\log_{10}$ air temperature +1.0 (°C)	0.947	1.000	
$\log_{10}$ solar radiation +1.0 (J/m^2)	0.698	0.815	1.000
$\log_{10}$ stream discharge (m^3/day)	-0.838	-0.858	-0.730

Table 2. Regression equation showing the relationship between dependent variable ($\log_{10}$ mean monthly water temperature) and independent variables ($\log_{10}$ mean daily air temperature; $\log_{10}$ daily solar radiation, and $\log_{10}$ daily stream discharge). R^2, the coefficient of multiple determination, is 0.918, meaning that the three independent variables account for 91.8% of the variance in water temperature.

Parameter	Estimate
Intercept	0.38831
β air temperature	0.8913
β solar radiation	-0.1161
β stream discharge	-0.03382

Interpretations of the model must be very cautious however, due to the high levels of intercorrelation between the three independent variables. Furthermore, it is important to realize that this model does not embody a mechanism; the three independent variables (air temperature, solar radiation, and flow) are simply correlates of water temperature.

The regression model was then used to predict water temperatures in the succeeding logging and postlogging years. Discrepancies between predicted and observed water temperatures can be ascribed to the effects of logging in the watershed. This assumes that such differences reflect changes in the watershed that altered the relationships between water temperature and the three predictive variables.

Predicted and observed water temperature show generally good agreement in the prelogging years (1971 to 1975, Fig. 8). Apart from some large discrepancies in 1972 which have no ready explanation, significant divergence first appeared in the summer of 1977, after approximately 16% of the basin had been clear-cut. Percentages of the basin clearcut have been adjusted to indicate the basin area above B-weir and are somewhat lower than percentage areas logged of the entire basin.

In succeeding years during logging (1978 to 1980), a general pattern of discrepancies is apparent (Fig. 9). Differences between predicted and observed water temperatures are greatest during the summer months, May through September, with June and July showing the greatest differences. The stream remains warmer than expected during October through December, but appears to cool to expected temperatures during January through March.

The differences between predicted and observed average water temperatures for the months June through August increase in proportion to the basin area logged from 1976 to 1980 (Fig. 10).

Stream temperatures were lower during the summer of 1981 compared to other logging years, and there is some indication that the differences between observed and expected stream temperatures decreased during this period (Fig. 10). The measure of logging activity used here, the proportion of the basin clearcut, is a very simple index. It does not take into account the possible effects of leave strips, slope exposure, or stream shading. However, logging in the Carnation Creek watershed has been largely confined to south-facing slopes where there are no appreciable leave strips.

Extensive growth of salmonberry (*Rubus spectabilis*) in 1980 and 1981 along reaches of the main creek and side channels probably increased stream shading, reducing direct sunlight to the stream which led to lowering of the stream temperature. Consistent with this speculation is a highly significant relationship between the observed temperature increases due to logging and the proportion of the streambank vegetated (Pearson's $r = 0.989$, $p < 0.001$, Fig. 11). (Only the streambank and side channels in those areas occupied by anadromous fish were included in this analysis.)

It is possible that the functional relationship between mean water temperature, mean air temperature, solar radiation, and flow has changed after extensive logging in the watershed. The expectation is that solar radiation becomes the principal determinant of water temperature once the forest canopy is removed (Anderson 1973). This hypothesis was examined by comparing the predictive regression equation already presented to a regression developed for during-logging years. Examination of the correlations between mean water temperature and the three predictive variables and of the regression equations (Table 3) indicates that the general form of the relationships has remained the same during logging, with air temperature continuing to be the best predictor of water temperature. Although solar radiation is more highly correlated with stream temperature in 1977 to 1979 than in 1973 to 1974, the magnitude of its regression coefficient indicates that it has remained a minor component of the model.

Predictive Equations for Maximum Stream Temperatures

Maximum stream temperatures can also be predicted from average air temperatures, solar radiation, and streamflow. Comparisons of equations developed for prelogging (1973 to 1974) and during-logging (1977 to 1979) (Table 4) indicate that the best correlate of maximum stream temperature changes from air temperature to solar radiation after logging has begun. The magnitude of the regression coefficients indicates that solar radiation has become a major component of the regression model. This is consistent with other studies that have shown that direct sunlight to the stream surface is the major determinant of maximum stream temperature (Brown 1969).

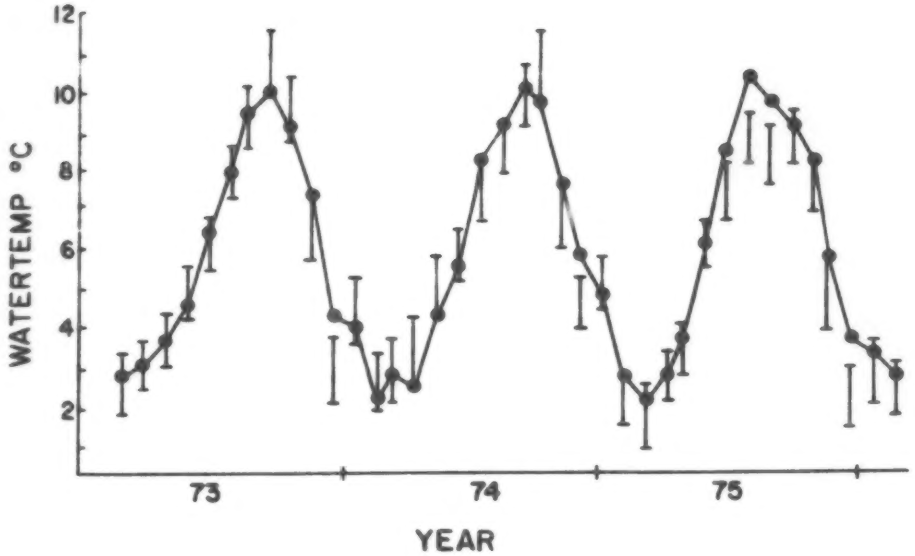

Fig. 8. Predicted and observed 30-day averaged water temperatures at B-weir for the years 1973 to 1975. Observed temperatures are shown as connected solid circles. Temperatures predicted by the multiple regression model (Table 2) are shown as 95% confidence intervals.

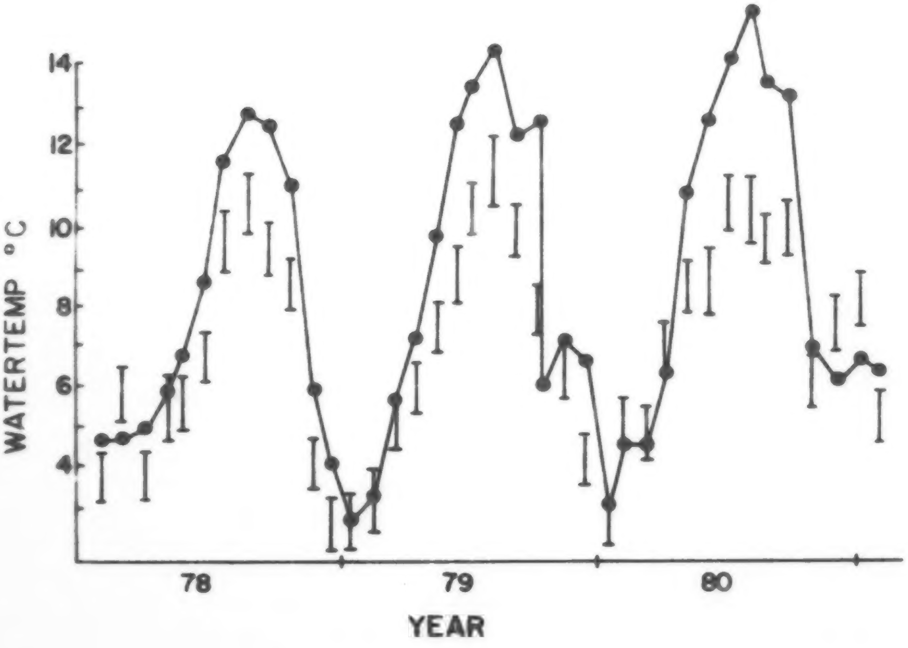

Fig. 9. Predicted and observed 3-day averaged water temperatures at B-weir for the years 1978 to 1980.

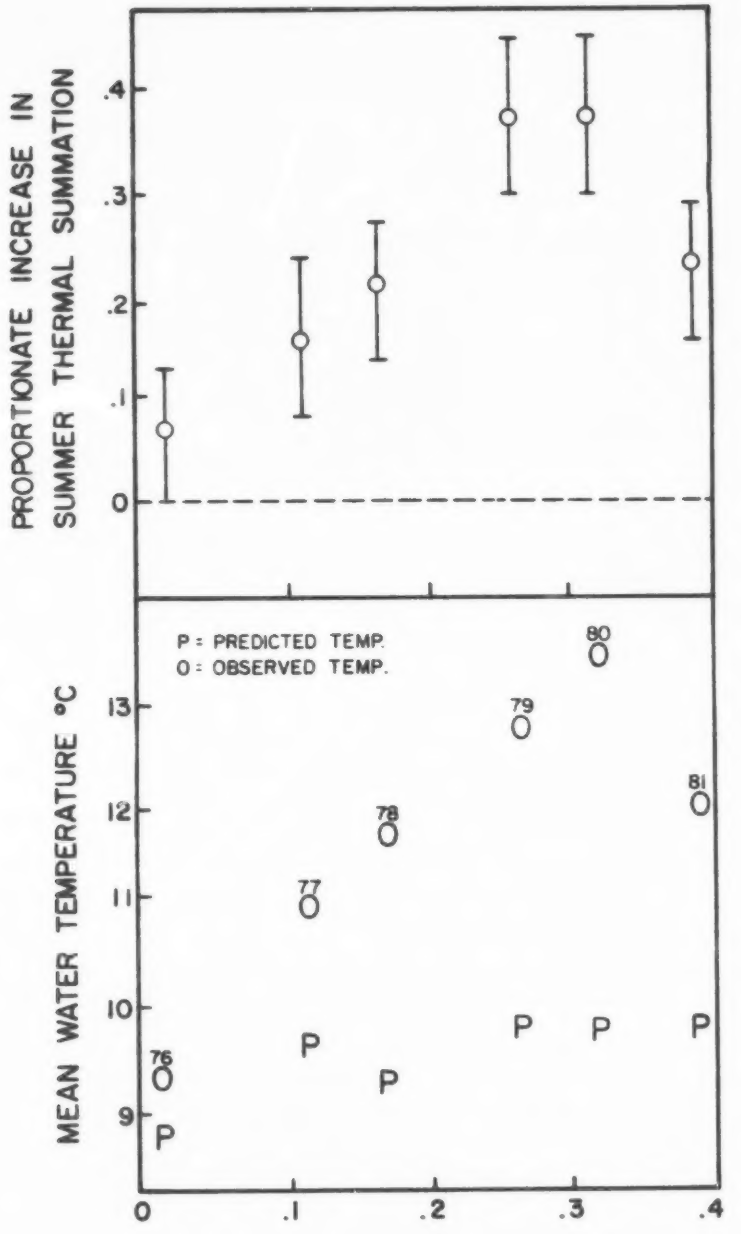

Fig. 10. Changes in the summer temperature regime of Carnation Creek mainstem at B-weir as functions of the proportion of the basin clearcut:

(a) Proportionate increase in summer temperature summations of centigrade degree days for June, July, and August. Increases were scaled relative to the prelogging (1971 to 1975) summer average.

(b) Observed and predicted summer mean water temperatures at B-weir.

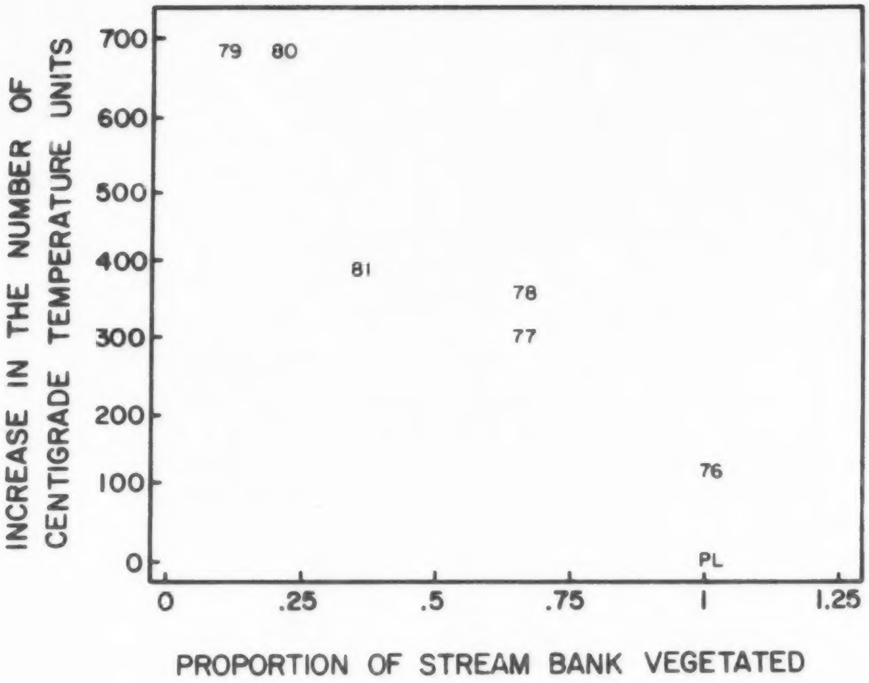

Fig. 11. Increases in summer thermal summation of centigrade degree days as a function of the proportion of the streambank vegetation. Devegetation of the streambank was due to logging. "PL" is the prelogging (1971 to 1975) summer average (June, July, and August).

Table 3. A comparison of correlates of water temperature and estimates of various parameters before timber harvest (1973 to 1974) and during timber harvest (1977 to 1979)*.

	Variable	Correlations	
		1973-1974	1977-1979
1. Pearson product moment correlations with $\log_{10}$ (water temperature +1.0) $^{\circ}$C			
$\log_{10}$ (air temperature +1.0)	$^{\circ}$C	0.947	0.953
$\log_{10}$ (solar radiation)	J/m^2	0.698	0.800
$\log_{10}$ (stream discharge)	m^3/s	–0.838	–0.671

	Parameter	Estimates	
		1973-1974	1977-1979
2. Regression equations	Intercept	0.38831	0.6220
	β air temperature	0.8913	0.7867
	β solar radiation	–0.1161	–0.06135
	β stream discharge	–0.03382	0.07433
	R^2	0.918	0.922

* Cumulative amount of basin clearcut:

1973-1974 = 0%
1977-1978 = 28%
1978-1979 = 34%

Table 4. A comparison of correlates of maximum stream temperature and predictive regressions for maximum water temperature before timber harvest (1973 to 1974) and during timber harvest (1978).

	Variable	Correlations 1973	Correlations 1978
1. Pearson product moment correlations with log maximum water temperature (°C). Critical ($p = 0.05$; 34 d.f.) = 0.330.			
$\log_{10}$ (air temperature)	°C	0.971	0.773
$\log_{10}$ (solar radiation)	J/m^2	0.717	0.818
$\log_{10}$ (stream discharge)	m^3/s	–0.849	–0.627

	Parameter	Estimates 1973	Estimates 1978
2. Multiple regression equations. (All terms are statistically significant at the 5% level of confidence.)	Intercept	0.3844	0.4780
	β air temperature	0.7825	0.2452
	β solar radiation	–0.0613	0.2418
	β stream discharge	–0.0295	0.0720

Effects of Logging on Thermal Summations

The effects of altered stream temperatures can be summarized by thermal summations over fixed periods. Accumulated centigrade temperature units (CTUs) have been tabulated for the May 1 through October 30 summer period (Table 5) and for the egg incubation period of coho salmon (Table 6). The data used for these calculations were 10-day, not 30-day, averages. The period of egg incubation was arbitrarily defined to begin with the date that 50% of the spawning female salmon had passed the counting fence upstream. The period ended in the following spring on the date when 25% of the merged fry that ultimately passed downstream were counted at the fish fence.

Logging has had a highly significant effect on the accumulated CTUs during the summer (Table 5). During the logging period 1976 to 1981, from 6.5% to 38.0% more CTUs than predicted were observed and the discrepancies increased in proportion to the basin area clearcut. Temperature-limited processes such as microbial and invertebrate respirations rates have probably been significantly affected by summer temperature increases of these magnitudes.

Logging has had a less pronounced effect on winter thermal summations (Table 6). In all winters in which logging has occurred (1976 to 1981), observed CTUs have been greater than predicted, but in only two of the five years are the differences statistically significant. The time of emergence has become progressively earlier since logging (Table 6), indicating that the required degree-days thermal summation for emergence is occurring sooner in the spring. However, the predicted CTUs have also increased with time, an indication that the warmer stream temperatures observed since logging are due in part to climatic variability, in addition to the effects of logging.

The consequences of earlier emergence are difficult to predict. In years when there are late-winter storms, early-emerging fry are probably flushed from the stream, leading to understocking of the stream with fry and ultimately to reduced smolt production. Early-emerging fry that remained in the stream during the logging period began growth three to five weeks earlier than late-emerging fry in the prelogging period. Both the understocking of the stream and the earlier inception of growth have had significant effects on coho populations in the stream which are considered further by Holtby and Hartman and Hartman and Holtby (these proceedings) and by Hartman et al. (in press).

DISCUSSION

As expected, logging has led to increased summer temperatures in Carnation Creek. During the summer, there have been logging-related increases in mean and maximum stream temperatures and increased diel ranges, due almost entirely to increased maximum temperatures. The effects of logging have been unexpectedly large considering that only 39% of the basin has been clear-cut (see Anderson 1973). This possibly resulted from the concentration of logging on slopes with southern exposures, close to the site of temperature measurement at B-weir (Fig. 1).

Summer temperature increases due to logging were proportional to the basin area logged. If this relationship is extrapolated to 100% clearcut, then an increase in the mean temperature of approximately 7°C in the May to October period is predicted. However, most of the additional clearcutting would be on north-facing slopes so the temperature increase that would result would likely be somewhat less. There are indications that the temperature increases moderated in the summer of 1981. It is unknown whether this decreased logging effect is spurious or if real, whether it is due to revegetation in the older harvested areas. Although the effects of 100% clearcut cannot be predicted with certainty, the magnitude of the potential temperature increases indicated by the responses observed thus far are alarmingly high.

Although we are clearly not in a position to construct an energy budget for Carnation Creek, there is enough circumstantial evidence about temperature determination to warrant some speculation. During the summer, Brown's analyses linking stream temperature to the direct incidence of sunlight (1969, 1970) apply to Carnation Creek. The apparent importance of air temperature in our regression model is most probably a spurious result of the correlation between solar radiation and air temperature. Strong circumstantial support for Brown's findings comes from the high correlations between the SA/VOL ratios of tributaries and their diel temperature fluctuations and from similarly high correlations between logging-related temperature increases and the proportion of the streambank that was vegetated. In months when there is little sunlight (December to February), stream temperatures during logging

Table 5. Effects of timber harvest on stream temperature from 1971 to 1981 during the period May 1 to October 31. Difference between the observed number of centigrade temperature units (CTUs) and the predicted CTUs are interpreted as the effects of timber harvest.

Summer of	Number of Centigrade Temperature Units			Observed minus Predicted	Observed CTUs minus Predicted CTUs divided by Average CTUs Before Timber Harvest
	Average Before Timber Harvest 1971 to 1975	Observed	Predicted (95% Confidence Interval)		
1971	1790.4	1783.2	• •	•	•
1972		1801.8	1728.7 (1595.6 to 1861.8)	—	—
1973		1768.4	1731.4 (1605.1 to 1857.7)	—	—
1974		1768.9	1717.6 (1589.9 to 1845.3)	—	—
1975		1829.7	1648.2 (1529.8 to 1766.6)	—	—
1976		1748.5	1631.5 (1519.2 to 1743.8)	117.0	0.065
1977		1992.1	1703.3 (1581.8 to 1824.8)	288.8	0.161
1978		1834.9	1464.3 (1358.3 to 1570.3)	370.6	0.207
1979		2317.9	1639.8 (1520.2 to 1759.4)	678.1	0.379
1980		2436.0	1755.6 (1637.3 to 1873.9)	680.4	0.380
1981		2085.6	1680.6 (1567.5 to 1793.7)	404.0	0.226

– not calculated

• insufficient data for calculation

Table 6. Changes in the rate of embryonic development of coho salmon as a function of changes in stream temperature induced by timber harvest.

		Duration of Embryonic Development				Centigrade Temperature Units (CTU) During Period of Embryonic Development			
									OCTU-PCTU
Winter of	Fraction of Basin Clearcut at Beginning of Winter	Immigration Date of Female Spawners*	Emmigration Date of Fry*	Elapsed Time (ET) (Days)	ET / PLET	Observed (OCTU)	Predicted (PCTU) (95% Confidence Interval)	OCTU-PCTU	Overall Average OCTU
70-71	0	305	132	192	--------	894.0	N/D	N/D	N/D
71-72	0	305	129	189	--------	784.0	991.7 (867.8-1115.6)	--------	--------
72-73	0	309	111	167	--------	804.5	866.1 (750.1- 982.1)	--------	--------
73-74	0	287	114	192	--------	902.3	1011.7 (884.3-1139.1)	--------	--------
74-75	0	307	112	170	--------	807.3	806.1 (690.8- 921.4)	--------	--------
		Prelogging Average PLET =		182	Average =	838.5			
75-76	0	285	120	200	1.099	1021.0	1026.0 (895.6-1157.1)	-5.0	–0.005
76-77	0.008	297	97	165	0.907	1020.2	927.2 (819.6-1034.8)	+93.0	0.102
77-78	0.108	296	97	166	0.912	983.6	859.1 (771.0- 947.2)	+124.5	0.137
78-79	0.168	309	106	162	0.890	789.7	705.6 (598.7- 812.5)	+82.1	0.090
79-80	0.263	294	100	171	0.940	987.9	868.9 (755.1- 982.7)	+119.0	0.131
80-81	0.323	306	82	141	0.775	1016.1	1003.8 (890.2-1117.4)	+12.3	0.014
					Overall Average =	909.9			

—— Not calculated.

N/D Insufficient data for calculation.

* Measurements of the duration of embryonic development begin the moment that 50% of the female coho spawners have passed upstream through the counting fence in the autumn and end the moment that 25% of the fry, progeny of those spawners, pass downstream through the counting fence the following spring. Julien dates are given in the table.

were close to those predicted. This is expected if increased sunlight to the stream was the major factor in logging-related temperature increases.

Research into the effects of logging on stream temperature have largely dealt with increased maximum stream temperatures that result from the removal of streamside vegetation (Chapman 1962; Levno and Rochacher 1976, 1969; Brown 1971; Brown and Krygier 1967, 1970; Lantz 1971; Ringler and Hall 1975). This is a legitimate concern in many climates since stream temperatures approach stress levels for salmonids during the summer even with complete canopy closure. Preservations of streamside vegetation is thus crucial in effective habitat management in such regions. However, in cool, wet climates such as those at Carnation Creek, it is unlikely that temperatures could rise high enough for sufficiently long periods to seriously harm salmonids.

The temperature of water in small tributaries of Carnation Creek, where the land has been denuded, occasionally increased above the temperature preferred by coho salmon, but it is unlikely that this was a serious problem for these fish. For example, even in the Alsea study where high temperatures over short periods were greater than the upper lethal limit for coho, no fish died, although they were less healthy and they grew less rapidly than they would have under better conditions (Moring and Lantz 1974). Since fish in Carnation Creek are subjected to temperature changes less extreme than those in the Alsea watershed, they probably endure the brief hot spells with even less trauma. However, the long-term effects of increased diel temperature fluctuations and moderate temperature increases on the salmon juveniles are unknown and merit further study. Furthermore, with regard to other biotic processes in the stream, the effects of increased average summer temperatures of the magnitudes observed in Carnation Creek are potentially large.

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CHANGES IN GROUND-SURFACE CHARACTERISTICS AND VEGETATIVE COVER ASSOCIATED WITH LOGGING AND PRESCRIBED BROADCAST BURNING

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ABSTRACT

Surveys of ground-surface conditions were conducted on six clear-cut blocks (cutblocks) within and on one cutblock immediately adjacent to the Carnation Creek Experimental Watershed. Surveys were done before clear-cutting, after felling and yarding, after broadcast burning, and after up to three additional years following logging or broadcast burning. Areas of haul roads were measured on aerial photographs, the coverage amounting to an average of 9.5% for all cutblocks. For interroad areas, data collected at points and milacre plots along transects showed that unlogged stands had little ground disturbance and nearly 100% vegetative cover. Logging reduced vegetative cover to 24% and increased mineral soil exposure to 16% and slash cover to 50%. Burning increased mineral soil exposure to 26%, decreased slash cover by half, and reduced vegetative cover to less than 5%. By two years after burning, vegetative cover recovered to about 30%. Erosion was noticeable only on burned cutblocks, occurring primarily after the first rainy season following the burn. These results and subsequent surveys and data from other investigators will facilitate comparisons of ground-surface changes with changes occurring in the stream.

INTRODUCTION

The amount and kind of changes in ground-surface characteristics induced by forestry operations are important for soil stability, surface-soil erosion, and site productivity. Many studies have related increased frequency of landslides to logging activity, particularly road building (Fredriksen 1970; Dyrness 1967; Megahan, Day, and Bliss 1978). Surface erosion is directly related to area of mineral soil exposed to raindrops and flowing water (Lowdermilk 1930; U.S. Environmental Protection Agency 1975). In addition, one of the main parameters in the Universal Soil Loss Equation, as formulated by Wischmeier and Smith (1965), is the cropping factor which is used to define the amount of mineral soil exposed and thus susceptible to detachment and transport by water (Wischmeier 1975). The amount of surface flow may be increased through plugging of pores and macrochannels by yarding activities (de Vries and Chow 1978) or by increased hydrophobicity induced by burning (DeBano 1969).

Harvesting and site-preparation practices in the Carnation Creek watershed have been monitored since 1976 to assess changes in ground-surface characteristics which would provide a basis for correlation of terrestrial events with changes in stream characteristics. Early work was conducted by D. Toews and J. Lamb, Canadian Dep. Fisheries and Oceans, in Cutblocks RR-10 and RR-8, harvested in 1975-1976 and 1976-1977, respectively. Our surveys have concentrated on later clearcuts.

STUDY METHODS

Information was collected along transects located to traverse logged and unlogged cutblocks from the bottom to the top, generally slightly off from

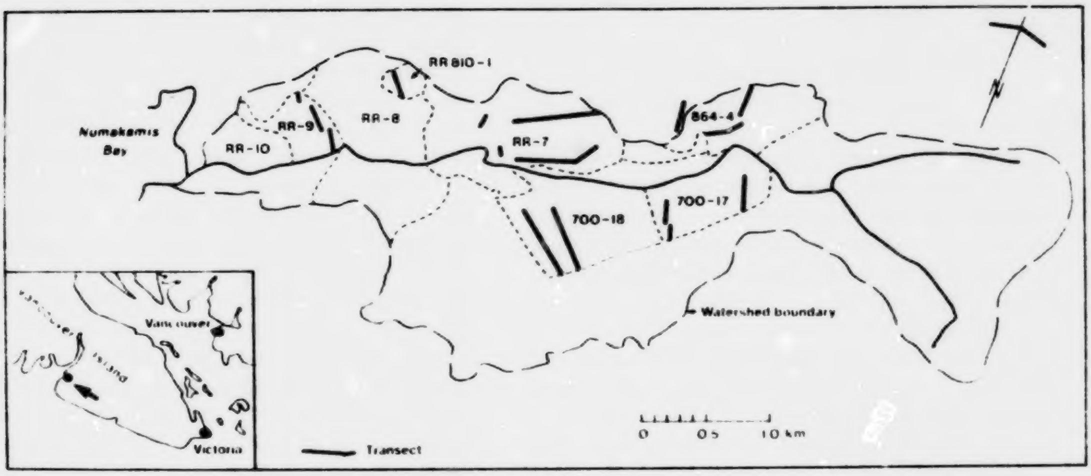
RR 810-1
Numakamis Bay
RR-9
RR-8
RR-10
RR-7
864-4
700-18
700-17
N
Watershed boundary
Vancouver
Vancouver Island
Victoria
Transect
0
0.5
1.0 km

Fig. 1. Map of Carnation Creek Experimental Watershed showing location of ground-surface survey transects within the cutblocks.

perpendicular to the contours (Fig. 1). At each 3 m mark on the transect, a point was defined by dropping a staff. The following features were recorded for each point if present:

A. **Soil Disturbance**

1. Undisturbed = no mineral soil exposed.
2. Gouges and deposits with mineral soil exposed:
   - Shallow = less than 5 cm deep.
   - Deep = 5 cm to 25 cm deep.
   - Very deep = more than 25 cm deep.
3. Shallow mixtures of organic matter and mineral soil.
4. Organic mat burned off to mineral soil.

B. **Rock**

1. Bedrock, bare or moss-covered.
2. Boulder = loose rock more than 25 cm diameter, bare or moss-covered.
3. Stone = loose rock 10 cm to 25 cm diameter, bare or moss-covered.

C. **Slash**

1. Fine = less than 5 cm diameter.
2. Coarse = more than 5 cm diameter.

D. **Natural Log** = a tree or portion of tree on the ground with sapwood decay.

E. **Stump**

F. **Tree bole**

G. **Root**

H. **Coverage of Broadcast Burn**

1. Burned
2. Unburned

I. **Percentage Slope**

J. **Aspect**

K. **Organic Mat**

1. Type:
   - Humified
   - Rotten wood
   - Mixtures of above

2. Thickness:

    - Thin = less than 10 cm
    - Thick = more than 10 cm

If other than mineral soil, the material underlying thin organic mats was described. For example, bedrock, natural logs, and roots were recorded as such, if underlying a thin mat. If no organic mat was present, a reason was given—such as a gouge, deposit, bedrock, stump, or root. Causes of disturbance (such as yarding and road construction) were given when this was clear. Additional information on the extent of roads and landings was gained from measurements on 1:15 840 aerial photographs. Milacre plots were surveyed around each 3 m transect point to estimate slash and vegetative cover by 10% classes and to count and measure tree regeneration.

Ideally, cutblocks were surveyed before logging, after logging, and after broadcast burning, if conducted. Several cutblocks were, however, initially surveyed at some point after logging. Table 1 indicates the surveys completed to date and those planned for the future. The last surveys will be run in 1983, at which time data will be available for the undisturbed stage, for immediately after logging or burning, and for 3 additional years. For summary purposes, all cutblocks surveyed at a particular stage of development have been combined. Because we did not sample every block at each stage, average trends are inferred rather than actual representations.

RESULTS

Soil Disturbance

Roads and Landings. Percentage of the ground surface of surveyed cutblocks made up of roads (including cutbanks and fillslopes) and landings averaged 9.5% (Table 2). The ground survey showed that all road and landing disturbance recorded was in the gouge and deposit categories and that 82.6% was very deep, 10.5% deep, and only 6.9% shallow.

Interroad Disturbance. Disturbance in interroad areas is shown in Fig. 2. The small (2.0%) amount of disturbance in unlogged stands resulted mainly from root overturns and ephemeral-stream erosion. Yarding activity increased this level to about 16%, with a wide variation from cutblock to cutblock. Burning increased mineral soil exposure to 26% by complete consumption of the organic mat by the fire. There was a tendency for these disturbance levels to increase with time after burning. Some of this increase might be attributable to overland flow and surface-soil erosion. Unlogged cutblocks had little visible erosion (0.5% of ground surface) and none was recorded for felled and yarded cutblocks. Logged and burned cutblocks surveyed immediately after burning (i.e., before the winter rainy season) had nearly twice the ground surface classified as eroded (0.9%). This increased to 4.1% 1 year after burning and 4.3% 2 years after burning. Data for 3 years after burning were available only for the most severely eroded cutblock, the proportion of surface classified as eroded amounting to 8.0%.

For all cutblocks, about 80% of the interroad disturbance was in the form of gouges and deposits. The remainder was organic mat burned off and shallow mixtures of organic and mineral soil. Of the gouges and deposits, 42% were shallow, 43% deep, and only 15% were very deep.

Slash Cover

Slash was generally associated with harvesting. However, recent windfalls with no sign of saprot were included as slash in the unlogged cutblocks to allow separation of this material from "normal" slash recorded in the same cutblocks after logging. Windfall of any consequence was present in only one unlogged cutblock and the average "slash" cover of 5% (Fig. 3) recorded for this stage was due mainly to that cutblock. For the logged stage, slash cover increased to over 50% with no change occurring in an additional year. Broadcast burning reduced slash cover to about 23%. The latter figure did not change appreciably within the subsequent 3 years (Fig. 3).

Vegetative Cover

Vegetative cover in the unlogged stage was close to 100% when all layers of vegetation were considered. The overmature nature of the stands was indicated by a relatively broken cover for the tree layer (Fig. 4). Logging reduced the tree layer to near 0% and total vegetative cover to 24%. Burning reduced total vegetative cover even further to less than 5%. Little increase was noted within a year of burning, but by the second year after burning, total vegetative cover had increased to 30%.

Table 1. Dates of surveys of ground-surface conditions—completed or planned.

Cutblock	Year Logged	Stage of Cutblock[a] U	L,0	L,1	L,2	L,3	B,0	B,1	B,2	B,3
SC-864-4	1977-1978	....	....	Oct. 1979[b]	....	....	Oct. 1979[b]	....	Apr. 1981[b]	Apr. 1982[b]
RR-810-1	1977-1978	....	....	....	....	....	....	Oct. 1979	Apr. 1980	Apr. 1981
RR-7	1978-1979	....	Sep. 1979	....	....	....	Oct. 1979	Apr. 1980	Apr. 1981	Apr. 1982
SC-700-18	1979-1980	Sep. 1979	May 1980	May 1981	Apr. 1982	Apr. 1983	....	....	....	....
RR-9	1980-1981	Apr. 1980	Sep. 1981	....	....	....	Oct. 1981	Apr. 1982	Apr. 1983	....
SC-700-17	1980-1981	May 1980	Sep. 1981	Apr. 1982	Apr. 1983	....	....	....	....	....
Near H-weir	[c]	Oct. 1979	....	....	....	....	....	....	....	....

[a] U = Unlogged
L = Logged
B = Broadcast burned
0, 1, 2, 3 = years after logging or burning

[b] Part of cutblock broadcast burned.

[c] Unlogged to present date.

Table 2. Percentage cover of roads and landings estimated from aerial photographs.

Cutblock	Roads and Landings (% cover)
SC-864-4	10.4
RR-810-1	5.2
RR-7	10.9
SC-700-18	8.9
RR-9	6.0
SC-700-17	8.4
Weighted average	9.5

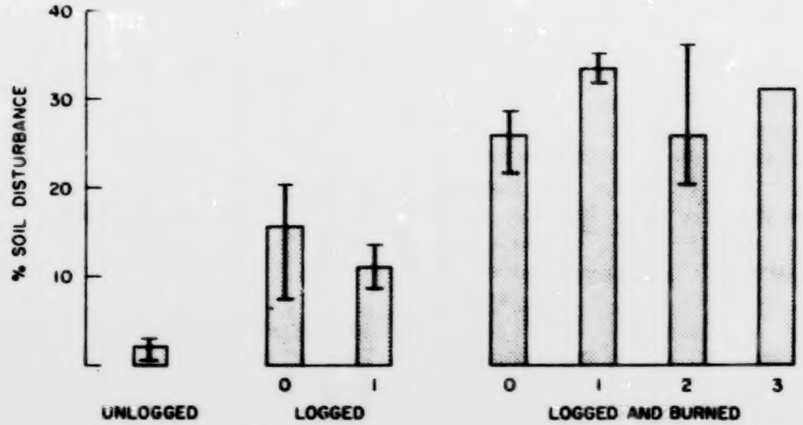

Fig. 2. Average and range of soil disturbance as a percentage of the area of surveyed cutblocks for 7 stages of development. Numbers for logged and logged and burned stages represent years since logging or burning.

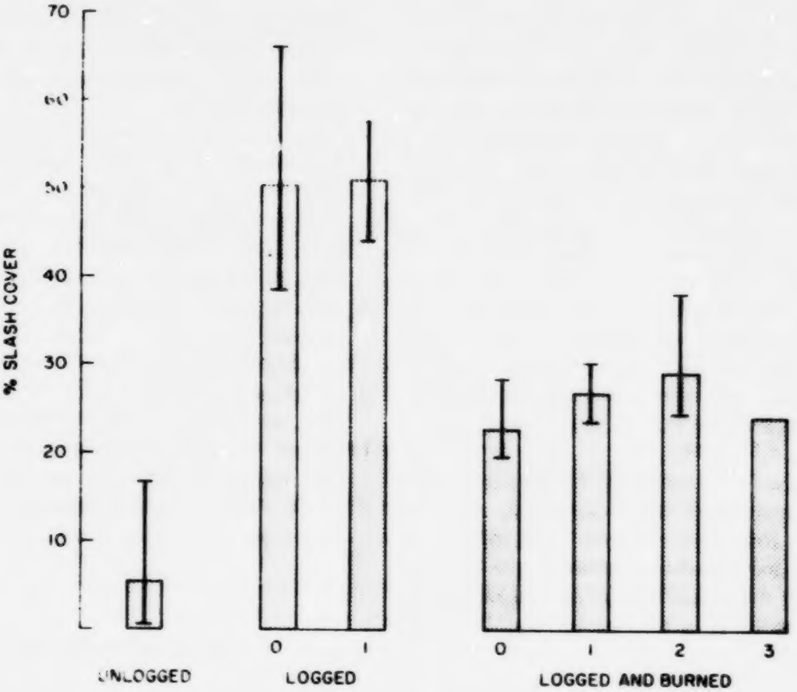

Fig. 3. Average and range of slash cover as a percentage of the area of surveyed cutblocks for 7 stages of development. Numbers for logged and logged and burned stages represent years since logging or burning.

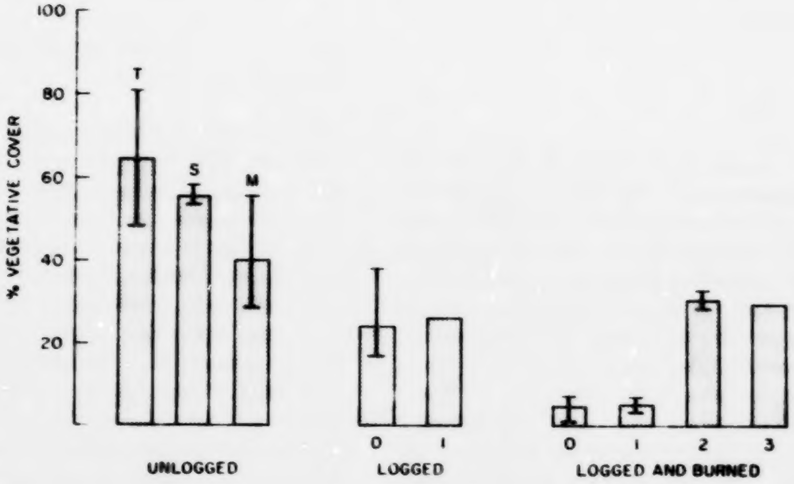

Fig. 4. Average and range of vegetative cover as a percentage of the area of surveyed blocks for 7 stages of development. Numbers for logged and logged and burned stages represent years since logging or burning. In the unlogged stage, T = Tree layer; S = Shrub and herb layer; M = Moss, liverwort, and lichen layer.

Organic Mat

In the unlogged stage, 49% of the undisturbed transect points were underlain by an organic mat exceeding 10 cm thick. Forty-two percent of the points had mats less than 10 cm and the remaining 9% of the points had no humus, e.g., points on bare roots, stumps, boles, and bedrock (Table 3). There was no marked change in these proportions after logging. After burning, however, the percentage of undisturbed (no mineral soil exposed) spots with no organic mat increased to a maximum of 20% 3 years after broadcast burning. The percentage of points with mats over 10 cm in depth did not, however, decrease markedly from that for the unlogged stage.

In the unlogged stage, 80% of the transect points with an organic mat were classified as humified material and 20% as rotten wood or a mixture of rotten wood and humified material (Table 4). Logging increased the proportion of the ground surface with rotten wood or a mixture to about 35% and burning to 45%.

Natural Logs

The condition of natural logs ranged from those with surface saprot to almost complete decay, even to the point of having a thin cover of humus, but still retaining a log form. The percentage of interroad ground surface covered by natural logs was 17% for the unlogged stage. This cover was reduced in the logged and logged and burned stages to 7% and 5%, respectively.

Bedrock Exposure

Bedrock was encountered infrequently and the results could be compared only within the same cutblocks. For instance, Cutblocks RR-9, SC-700-17, and SC-700-18 were all surveyed from the unlogged to the logged stage. Bare and moss-covered bedrock increased from 1.8% of the surface in the unlogged stage to 2.6% in the logged stage. Total rock surface, including stones and boulders, declined from 8.1% to 7.6% during the same time. Cutblocks RR-9 and RR-7 were surveyed from the logged stage to logged and broadcast burned. In the logged stage, bedrock exposure was 2.1%, and in the stage immediately after burning, it was 2.5%. Total rock surface increased from 4.0% to 9.0%. Cutblock RR-7 was also surveyed for 2 years after burning. The bedrock surface cover for the four stages for RR-7 only were (total rock cover in parentheses): logged = 1.5% (3.5%); burned, 0 years = 2.0% (9.3%); burned, 1 year = 2.0% (6.8%); burned, 2 years = 3.8% (8.6%).

Tree Regeneration

Immediately after logging and before burning, the only regeneration was advance, i.e., that remaining from the original stand. Some of these stems were of poor form. Considering only those of good form, 4.4% of milacre plots of recently logged cutblocks were considered restocked. One year later, cutblocks surveyed had a total of 25.1% milacre stocking made up of both new and advance regeneration. Cutblocks broadcast burned had some trees that escaped the burn, so that an average milacre stocking of 1.1% was present immediately following the burn. This stocking increased to 3.2% after an additional year and to 73.4% after 2 years. Planting increased the former percentage to 39% and the latter to 78%.

SUMMARY AND DISCUSSION

In the natural state, forest stands in the Carnation Creek watershed were overmature and, as a result of windthrow, possessed a broken tree cover. However, when shrubs, herbs, bryophytes, and a 98% organic mat coverage are considered, the mineral soil was afforded almost complete protection. A large portion of the organic mat was humified material, with the remainder rotten wood or a mixture of the two. Another dominant feature of the natural stand was the high cover of old logs or boles of trees previously windthrown.

Clear-cut logging reduced tree cover drastically, increased other vegetative cover, and further reduced the protective features of the organic mat through gouges and deposits from road and landing construction and felling and yarding operations. Over 9% of cutblock surfaces consisted of haul roads and landings and a further 16% mineral soil exposure resulted from the felling and yarding operations. Compensating for the loss in vegetative cover and the increase in mineral soil exposure was an increase in the accumulation of slash to over 50% of the ground surface. Felling and yarding also increased the cover of rotten wood relative to humified material. Some of this increase likely came from the breakage during felling of snags and trees with heartrot. Another source was probably decayed, natural logs broken apart and scattered during yarding. The coverage of natural logs was certainly reduced in the logged stage

Table 3. Depths of organic mats at undisturbed points.

Stage	Basis–No. of Undisturbed Points[a]	Depth (%)			
		No Organic Mat	Less Than 10 cm Thick	More Than 10 cm Thick	Not Able To Determine[b]
Unlogged	642	8.7	42.1	49.2	0.0
Logged, 0 year	775	11.5	34.5	52.3	1.7
Logged, 1 year	341	6.7	40.8	51.3	1.2
Burned, 0 year	398	11.8	32.9	55.3	0.0
Burned, 1 year	316	17.7	34.2	48.1	0.0
Burned, 2 years	408	18.4	38.0	43.6	0.0
Burned, 3 years	69	20.3	30.4	49.3	0.0

[a] Points with no mineral soil exposed.

[b] Not able to determine because of slash accumulations.

Table 4. Type of organic mat.

Stage	Basis–No. of Undisturbed Points[a]	Type (%)			
		Humified	Rotten Wood	Mixture of Humified and Rotten Wood	Layer of Ash
Unlogged	586	79.5	11.8	8.7	0.0
Logged, 0 year	673	66.1	21.4	12.5	0.0
Logged, 1 year	314	64.0	22.9	13.1	0.0
Burned, 0 year	351	55.5	28.8	14.8	0.9
Burned, 1 year	260	55.4	22.7	21.9	0.0
Burned, 2 years	333	58.0	20.4	21.6	0.0
Burned, 3 years	55	41.8	30.9	27.3	0.0

[a] Points with organic mat and no mineral soil exposure.

from that in the unlogged. Logging was associated with a small increase in the percentage of exposed bedrock (bare or moss-covered) but not in the proportion of ground surface with plainly visible surface-soil erosion.

Broadcast burning produced several important changes in ground-surface characteristics. Vegetative cover was reduced to less than 5% and slash cover by half to about 23%. At the same time, mineral soil exposure was increased to about 26%. Thus, the soil surface immediately following broadcast burning was most susceptible to rain-drop impact and overland flow. Surveys did show an increase in mineral-soil exposure after the first winter rainy season but this increase did not carry through to the next year. Burning did increase bedrock exposure but the amount of surface involved was surprisingly small. When the slopes are viewed from the valley floor, the cover of exposed bedrock seems much higher. Apparently, the cliffy nature of bedrock exposures creates a high visual impact disproportionate to its actual vertical projection. Burning was definitely associated with an increase in plainly visible signs of surface-soil erosion.

Once all surveys are complete in 1983 and in conjunction with the revegetation (King 1982) and other studies, we will be able to develop a cumulative picture of mineral-soil exposure for the whole watershed from 1970 to the present. This will facilitate comparisons of ground-surface changes with those changes occurring in the stream.

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QUESTIONS
TO R.B. SMITH AND E.F. WASS

Question *(T. Harding (?))*: I was under the impression that Carnation Creek watershed does not contain a large quantity of fluvial- or glacial-deposited materials and that the potential for erosion is quite low.

Answer *(C. Scrivener)*: It is, it's very low, really. I would say that the observed differences in soil deposits between Carnation Creek and the Queen Charlotte Islands might contribute to an understanding of the different types of processes that go on in these areas after logging. It might help us understand better the reason for the massive slumps that have been observed immediately after or the following winter after logging in Rennel Sound on the Charlottes. Eugene Hetherington has shown differences in the groundwater levels in postlogging conditions, even on the slopes. I guess the general theory is that a few years after logging the root systems that are left with the stumps started disintegrating and then you get mass movements afterwards. Rennel Sound is indicating quite clearly that you get a lot of mass movement immediately afterwards. And Eugene has evidence to show what the mechanism might be. So even though we don't see mass slumping in Carnation Creek, it's certainly got very strong extrapolatable management implications there in places like the Charlottes where you do get mass movements.

REVEGETATION
OF CARNATION CREEK WATERSHED

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ABSTRACT

A study was established to monitor the recolonization by vegetation following logging and burning in the Carnation Creek watershed. To date, a total of 255 plots have been located along predetermined transects in 10 settings that have been logged and burned for slash removal. Vegetation analyses were conducted according to a schedule of year 1, 2, 3, 5, 10, and 15—with year 1 being the spring following the last disturbance. The data were processed into a computer system for storage, analyses, and retrieval. A preliminary indication of the vegetation succession is given for only one setting in which the vegetation assessments have been conducted for three consecutive years. *Rubus spectabilis*, *Blechnum spicant*, and *Polystichum munitum* were most common on wetter sites, while *Gaultheria shallon* and *Vaccinium ovatum* were more common on drier sites. The setting was planted with a variety of tree species on the floodplain and with *Pseudotsuga menziesii* on upland areas. Initial indications are that seedling survival is low, possibly due to desiccation.

INTRODUCTION

Logging commenced in the Carnation Creek watershed during 1975, according to a plan proposed by MacMillan Bloedel Ltd., Cameron Division, and approved by members of the task force engaged in studying the effects of forest harvesting on salmonid fish populations. In general, the logging plan and methods of harvesting follow commonly-used techniques for timber removal in coastal forests. In two settings, however, tree falling and yarding across streams were permitted (MacMillan Bloedel Ltd. 1979) to facilitate certain studies related to fish populations. Prescribed burning was planned as the primary means of removing logging debris and was to follow the logging as soon as suitable burning conditions became available. Since logging was done during the winter, burning was normally attempted the following autumn. Two methods of burning were proposed—broadcast either by hand or from a helicopter and pile burning. The decision on technique was normally made by the forest company, but topography and other site conditions were usually the governing factors. With a couple of minor exceptions on the creek floodplain, no scarification other than what may occur during the logging operation was planned. Reforestation was to be the responsibility of the forest company and could be either through hand planting or by natural means as governed by the B.C. Ministry of Forests. Where planting was to be done, the species selection was to follow the guidelines suggested by Klinka (1977).

The rate, timing, and species of invading vegetation following slash burning (or logging if burning was not prescribed) has several potentially important influences that affect not only the success of reforestation but also the stream-water quality and quantity and, therefore, the fish populations. The vegetation aids in stabilizing the disturbed soil surface, in controlling the amount and rapidity of water runoff and/or infiltration, in attracting fauna (including insects, birds, and mammals), in reducing insolation at the soil surface, and in increasing evapotranspiration. All of these factors interact with each other to a greater or lesser degree, some being advantageous and others deleterious, and the degree will vary through the different successional stages.

The species of plants invading the area depend on a host of factors. Initially it depends on propagule material available, which in turn is dependent on such factors as the time or season of burn, the intensity of burn, the length of time and growing conditions between logging and burning, the moisture conditions following the burn, the amount and type of latent viable propagules remaining after burning, the amount and type of importable material which often is related to the vegetation types surrounding the area, and the direction and velocity of wind at the time of seed release. Initial invasion will continue until competition for space, water, soil nutrients, etc., becomes limiting. As vegetation develops, the microsite conditions change and those species intolerant to the change are eliminated. Eventually, only species capable of becoming established in shaded conditions will invade. The successional sequence will continue until a stable state is attained where the species are in equilibrium. Unless site factors are altered drastically, such as through erosion, it can be assumed the stable vegetation will have a strong resemblance to the forest prior to cutting.

A study was implemented to monitor the revegetation under the various treatment conditions (logging and burning) imposed on the existing stands. Most settings for logging had one dominant aspect, but topographic variations occurred in each setting. Also, the degree of burning was not uniform over an entire setting, as this depended on the amount and size of slash, the moisture conditions, the presence of living material, etc., which were not evenly distributed. The primary objectives of the study included documenting the vegetation development on the settings and recording the success of reforestation under different successional sequences, except that no special provisions were made for assessing success of hand-planted trees.

METHODS

Transects were laid out usually the spring following logging and burning. In general, these transects were preselected, with the number, length, and arrangement being dependent on the size and shape of the setting. However, when locating them in the field, it was sometimes necessary to make minor adjustments in respect of topographic conditions (e.g., cliffs). The objective was to provide enough transect line to cover most of the variable conditions and to allow for a sufficient number of plots suitable for statistical analyses. This necessitated replicated plots on at least the more prevalent site types that occurred in the setting. The transects were also located back from the edge of the setting to minimize any edge-effect.

Plot-center points were located along the transects at 30 m or 50 m intervals, depending on setting size and variability or length of transects. Metal posts were used to form a permanent marker and were painted and flagged to facilitate relocation in subsequent years. The sample plot design, as portrayed by Lafferty (1972), was adopted. This consisted of a 16 m^2 plot layed around the center point and parallel to the transect line. The plot was then divided into four subplots (quadrats) of 4 m^2 each for sampling woody vegetation. The subplot corners were also staked to permit relocation during subsequent sample years. A 1 m^2 subplot was located in each outer corner (Fig. 1) for sampling nonwoody vegetation. These subplots were relocated each year of sampling by using a special plot frame designed for the purpose.

Vegetation assessments commenced with year 1 being the spring after the last disturbance (burning if prescribed, otherwise logging). The assessments were normally made from about mid-May through June of each year on the following schedule: year 1, 2, 3, 5, 10, 15, etc. For each assessment, the species and percent cover for all species and the height of woody plants by height classes (1 = 0 to 8 cm, 2 = 9 to 15 cm, 3 = 16 to 30 cm, 4 = 31 to 60 cm, 5 = 61 to 120 cm, 6 = 121 to 200 cm) were recorded. A 35 mm photograph of each plot was taken during each assessment from a permanently marked point using a hand-held camera equipped with a 28 mm wide angle lens. Either at the time of plot establishment or during the first vegetation assessment, certain site conditions, such as degree of burn, evidence of erosion, amount of exposed rock, aspect, elevation, and moisture-related factors, were recorded for each quadrat. A field data collection card was devised so that the data could be more easily processed into a computer.

To date, 255 plots have been laid out in 10 settings and the vegetation measured. Of these, 116 plots have been assessed on three consecutive years, 76 plots on two years, and 63 plots on one year. Since each plot consists of four quadrats, the data base is four times the number of indicated plots. However, for the purposes of this presentation, only one setting with three years of data will be reported on.

Logging setting RR-8 consisted of a southerly-facing slope extending from the creek channel at about 8 m above sea level (a.s.l.) to about 274 m a.s.l., comprising about 61 ha. It was clear-cut using high lead and grapple-yarding techniques during the winter of 1976-1977. In this setting, it was permissable to fall and yard trees through streams. Broadcast burning with a helicopter was conducted in September 1977, with an estimated 70% of the area being successfully burned (MacMillan Bloedel Ltd. 1979). In the spring of 1978, 57 plots were established at 30 m intervals along transects, as indicated in Fig. 2. For the purposes of tentative analyses, the setting was divided into subunits based on site characteristics (Fig. 2). Subunit 1 included the floodplain of Carnation Creek, was generally level, subjected to periodic flooding and high water table, received moisture from upslope positions, and supported a mixed conifer and hardwood forest with an understory of *Rubus spectabilis* (see Appendix for common plant names) and *Blechnum spicant* prior to logging (Oswald 1975). Subunit 2 consisted of the lower slope which received moisture from upper slopes and supported a western hemlock-amabilis fir/deer fern association (Oswald 1973). Subunit 3 was the midslope and supported western hemlock/salal. Subunit 4 was a midslope wetland which mostly supported western hemlock, western red cedar, and amabilis fir with an understory of deer fern and sword fern. Subunit 5 was the upper slope which supported primarily Douglas-fir/salal.

RESULTS

Seven plots (28 quadrats) were included in Subunit 1. Only 8% of the quadrats in this subunit were burned and these mostly had a low fire intensity. At the first-year assessments, *Rubus spectabilis* and *Polystichum munitum* had the highest frequencies, 57.1% and 60.7%, respectively (Fig. 3), and provided the most cover, 11.9% and 11.2%, respectively (Table 1). *Ribes bracteosum*, *Galium boreale*, *Tiarella trifoliata*, and *Blechnum spicant* were also fairly common, occurring in more than 30% of the plots; however, their coverages ranged only from 2.0% to 5.6%. *Ribes bracteosum* and *Gaultheria shallon* had more height growth than *Rubus spectabilis*. During February of the following year, this subunit was flooded and the water table remained above or near the ground surface until early spring. This appeared to be detrimental to *Polystichum munitum*, but advantageous to *Blechnum spicant*. Also, *Galium boreale*, *Epilobium* spp., and, to some extent, *Sambucus racemosa* spread over more of the area, but all three had reduced frequencies the third year. In the second year, eight species were encountered that were not present the first year, but five species from the first year were lost. The shrub coverage increased the third year, while the forbs increased in frequency but only marginally in coverage. The most prevalent tree seedlings were *Thuja plicata* which occurred in 32% of the quadrats and had a height of about 23 cm. The frequency fell to 17.8% in the following two years, while the height growth increased to 79 cm by the third year. *Tsuga heterophylla* seedlings were present the first year, but absent, possibly due to flooding, in subsequent years. At least some of the *T. plicata* and *T. heterophylla* seedlings were the result of planting in the spring of 1978, year 1 of vegetation sampling, when this subunit was planted with these two species, in addition to *Pseudotsuga menziesii*, *Picea sitchensis*, and *Abies grandis* (MacMillan Bloedel Ltd. 1979). None of the latter three species were observed in the quadrats. *Alnus rubra* was evident the second year and, by the third year, had nearly three times the height growth of *T. plicata*. In this portion of the setting, *A. rubra* was notched with an axe and squirted with a herbicide (Tordon 22K) six months prior to logging (MacMillan Bloedel 1979).

On the lower slope, Subunit 2, 11 plots (44 quadrats) were put in place. The success of burning was higher than in Subunit 1, with 52% of the quadrats being burnt, although the intensity of burn was mostly low (Figs. 4, 5). *Gaultheria shallon* and *Blechnum spicant* were the most abundant species in frequency and percent cover (Table 2) during the first year. These species progressively increased in areal coverage over the three-year period; however, their frequencies were somewhat inconsistent. *Rubus spectabilis* and *Vaccinium ovalifolium* were also common and showed general increases in frequencies and percent covers over the three-year period but, for the most part, had low areal coverages. The height growth of the *Vaccinium* spp. was rather variable (Table 2), the inconsistencies possibly being the result of dieback, snow damage, or browse. Seven new species were encountered the second year, with the loss of only one species; but of the new species, only three persisted into the third year. Three additional species were observed in the third year. *Tsuga heterophylla* was the primary invading tree species and the height growth increased over the three-year period, but the frequency dropped the third year. This subunit was planted with *Pseudotsuga menziesii* during the spring of 1979. Conceivably, no seedlings were placeu in any of the plots because they should have appeared at least in the second-year samples. One *Taxus brevifolia* occurred in one quadrat that survived the cutting and burning.

Twenty-five plots (100 quadrats) were placed in Subunit 3, the midslope position. This subunit experienced the highest burn coverage, with 93% of the quadrats being burnt and the intensity was low to moderate on most (Fig. 6). *Gaultheria shallon* was the most frequent species and provided the most coverage, with a progressive increase over the three-year period (Table 3). *Blechnum spicant* was also common and increased in frequency and percent cover over the three years, but was less pronounced than in Subunit 2. *Vaccinium ovatum* increased in areal coverage here, while it decreased in Subunit 2 over the three years. *Epilobium* spp. and *Senecio* spp. had high frequencies the second year, but the *Senecio* was not observed the third year. *Pseudotsuga menziesii*, mostly as a result of planting, occurred in 44% of the quadrats the second year, but dropped out of some and had only marginal height growth the third year. *Tsuga heterophylla* and *Abies amabilis* were present in only a few quadrats the second year and *A. amabilis* was not observed the third year.

The midslope wetland (Subunit 4), based on 4 plots (16 quadrats), had a 62.5% success of burn, mostly of low intensity. *Rubus spectabilis* and *Blechnum spicant* had the highest frequencies the first two years, although *Epilobium* spp. was also quite frequent the second year (Table 4). This area was affected by high rainfall in late winter and early spring of the second year. This may have caused the reduction in *Blechnum spicant*, but it is opposite of what happened in Subunit 1. *Gaultheria shallon* increased significantly in frequency the second year, but became less common the third year, even though its coverage increased. *Pseudotsuga menziesii* was the most frequent tree species (probably due to planting) the second year, but there was a significant reduction the third year. *Thuja plicata* and *Tsuga heterophylla* were also present. On the third year, there was a high frequency of unidentified seedlings, mostly in the cotyledon stage, which normally experience a high rate of mortality.

Ten plots (40 quadrats) were located on the upper slope, Subunit 5. The fire intensity was moderate to high and 87.5% of the quadrats were burned (Fig. 7). *Gaultheria shallon* and *Epilobium* spp. had the highest frequencies and provided the most cover, although both were slow in developing (Table 5). In general, this subunit had the lowest vegetative cover within the setting and only had 5 species present the first year, 15 the second, and 17 the third. *Senecio* spp. again had a high frequency in the second year, but was not observed the third year. *Pseudotsuga menziesii*, largely as a result of planting, was the only tree species observed the second year. The frequency was reduced the third year and there was no increase in height growth. Unidentified seedlings occurred in some quadrats the third year.

DISCUSSION

The study of plant succession following logging and burning is in its early stages and any results or trends arising at this time can only be tentative. At least five years data are required and more than one setting must be analyzed in order to get a reasonable indication of trends. *Rubus spectabilis*, *Blechnum spicant*, and *Polystichum munitum* had their greatest degree of success on the more moist sites and *Gaultheria shallon* and *Vaccinium ovatum* on the drier sites. Since the fire intensity was generally low, it may be assumed that much of the initial vegetation came from root stocks that survived the disturbances. Although these species, as well as others, were perhaps more abundant in the original stands, many of the plants were rooted in logs and stumps, and these most likely would not survive the logging and burning either directly from the disturbance or from subsequent desiccation.

Also, a certain amount of seed of various species may have been laying dormant in the litter and duff layers and, where this was not burned, the seeds could germinate. Many of these, however, were probably desiccated, particularly on the south-facing slopes, and the plants never got established. This may, in part at least, account for the relatively large number of species occurring on the floodplain site where desiccation was less severe.

Some species were presumably blown in from adjacent or nearby areas. *Senecio* spp. was a good example. It comes in the second year with fairly high frequency, but was not found the third year. Its absence the third year was not clear, even though it was an annual, as there was plenty of room for it since rarely was even half of a quadrat covered with vegetation. In fact, it was not certain where the seed came from, as it was not observed in the original stand, except in a few disturbed areas. Fireweed, included here with *Epilobium* spp., was normally thought of as an early invader of burned areas. As indicated by this study, it is slow in getting established, at least on south aspects. It was frequently present in mature stands and should be readily available for occupying disturbed areas.

For the most part, tree regeneration perhaps appeared somewhat less than expected since the burn intensity was mostly low and several quadrats were not burned at all. In most places, mineral soil was exposed through the logging operations so that an adequate seedbed should have been available. Germination would normally occur prior to the date of vegetation assessment so that a larger number of seedlings in their cotyledon stage would have been anticipated. Admittedly, the survival of the seedlings would be jeopardized by desiccation during the summer.

However, once established, the growth of the seedlings on the different sites followed the expected pattern in that the floodplain area provided the best potential conditions for tree growth and seedlings found here had more height growth than those upslope. Similarly, those on the lower slope had more height growth than those on mid- and upper-slope positions. The seedlings on the midslope wetland, at least *Pseudotsuga menziesii*, were taller than on other midslope positions.

Another potential factor in inhibiting tree establishment was the growth of shrubs, especially on the floodplain site. *Rubus spectabilis* was perhaps the most important in this regard, as it appeared to dominate the vegetation. Conifer trees have an additional handicap in that *Alnus rubra* also grows very well on good sites—in fact it grows faster than the conifers and will further retard the more desirable species. On the other hand, *Alnus rubra* is capable of symbiotic nitrogen fixation which can serve to the benefit of conifers as long as the density of *A. rubra* is not too great.

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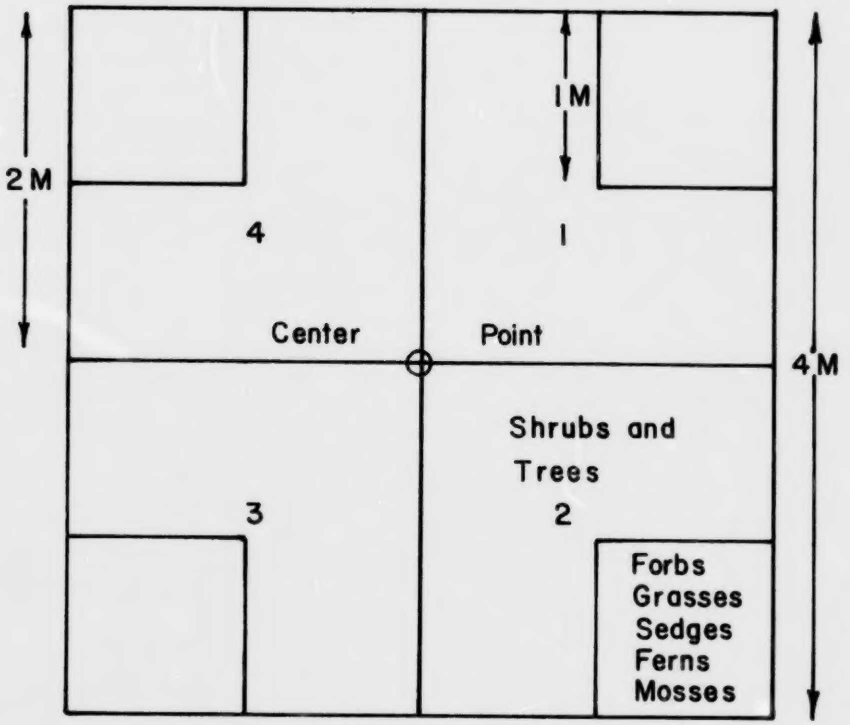

2 M
I M
4 M
4
I
3
2
Center
Point
Shrubs and
Trees
Forbs
Grasses
Sedges
Ferns
Mosses

Fig. 1. Diagram of plot and quadrats.

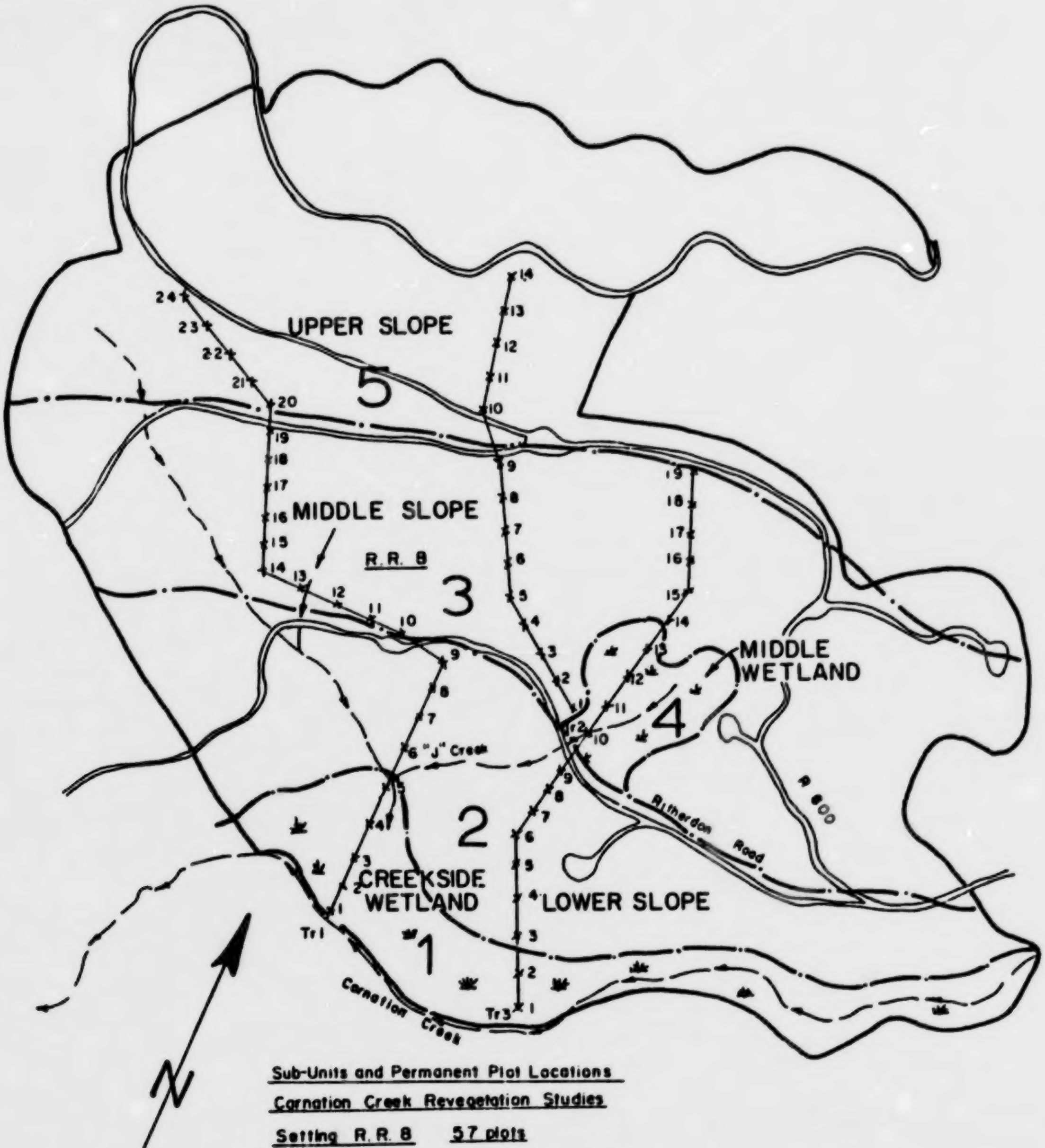

UPPER SLOPE
5
MIDDLE SLOPE
R.R. 8
3
MIDDLE WETLAND
4
2
CREEKSIDE WETLAND
LOWER SLOPE
1
"J" Creek
Carnation Creek
Ritherdon Road
R 800
Tr1
Tr2
Tr3
N
Sub-Units and Permanent Plot Locations
Carnation Creek Revegetation Studies
Setting R.R. 8 57 plots
Plots established April 26 to May 10, 1978
Metal stakes, blue paint / flagging

Fig. 2. Subunits and permanent plot locations, Carnation Creek revegetation studies, setting R.R. 8, 57 plots. Plots established April 26 to May 10, 1978; metal stakes, blue paint/flagging.

Fig. 3. Unburned creekside floodplain plot:

Upper is first-year assessment with 8% shrub cover (mostly of *Rubus spectabilis* and *Sambucus racemosa*) and 26% forb cover (mostly of *Polystichum munitum* and *Blechnum spicant*).

Lower is third-year assessment with 31% shrub cover (mostly of *Sambucus racemosa* and *Rubus spectabilis*) and 31% forb cover (mostly of *Polystichum munitum* and *Blechnum spicant*).

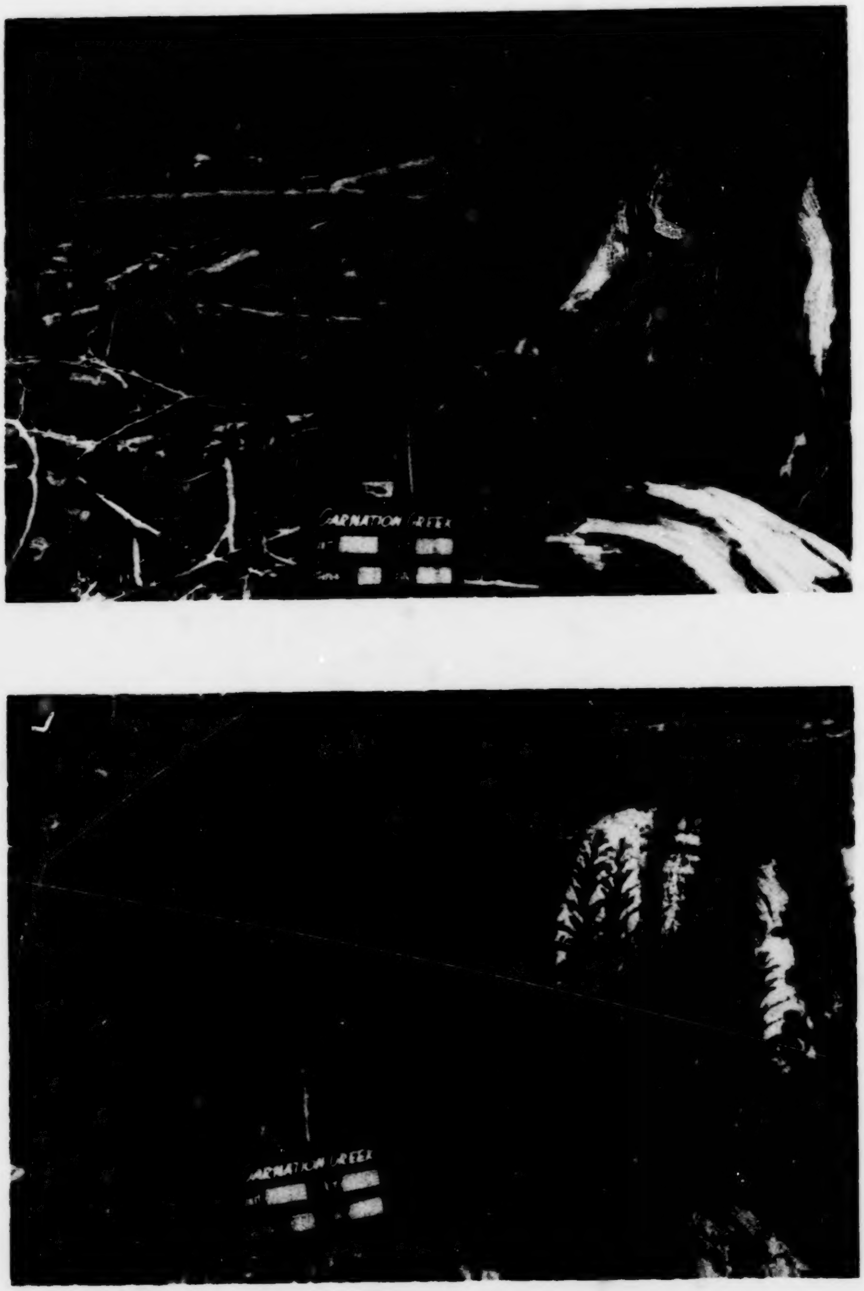
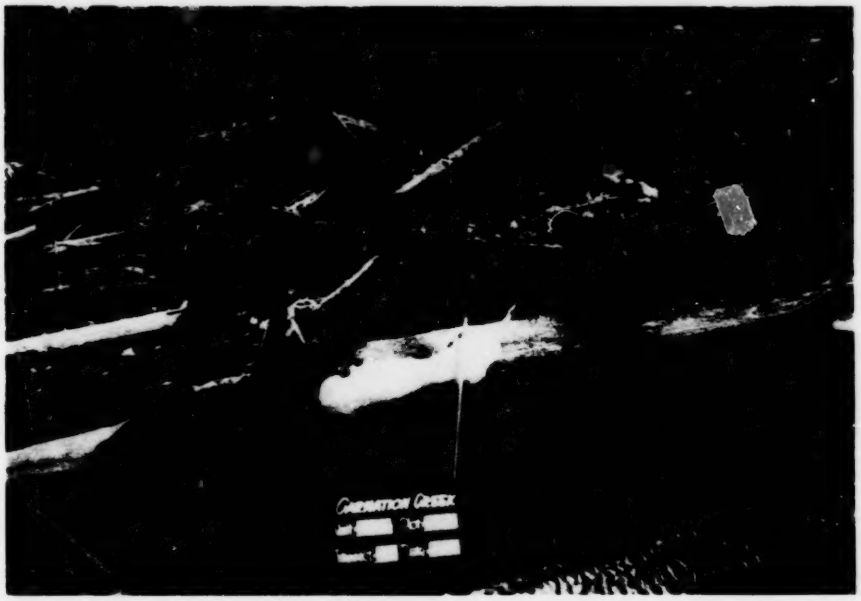


Fig. 4. Lower-slope plot with low intensity burn:

Upper is first-year assessment with 4% shrub cover (mostly of *Gaultheria shallon*) and 1% forb cover (mostly of *Blechnum spicant*).

Lower is third-year assessment with 20% shrub cover (mostly of *Gaultheria shallon*) and 19% forb cover (mostly of *Blechnum spicant* and *Epilobium angustifolium*).



CARNATION CREEK
Plot

CARNATION CREEK
Plot

Fig. 5. Lower-slope plot with moderate intensity burn:

Upper is first-year assessment with 1% shrub cover (mostly of *Gaultheria shallon*) and 7% forb cover (mostly of *Blechnum spicant*).

Lower is third-year assessment with 18% shrub cover (mostly of *Rubus parviflorus* and *Gaultheria shallon*) and 20% forb cover (mostly of *Blechnum spicant* and *Epilobium angustifolium*).

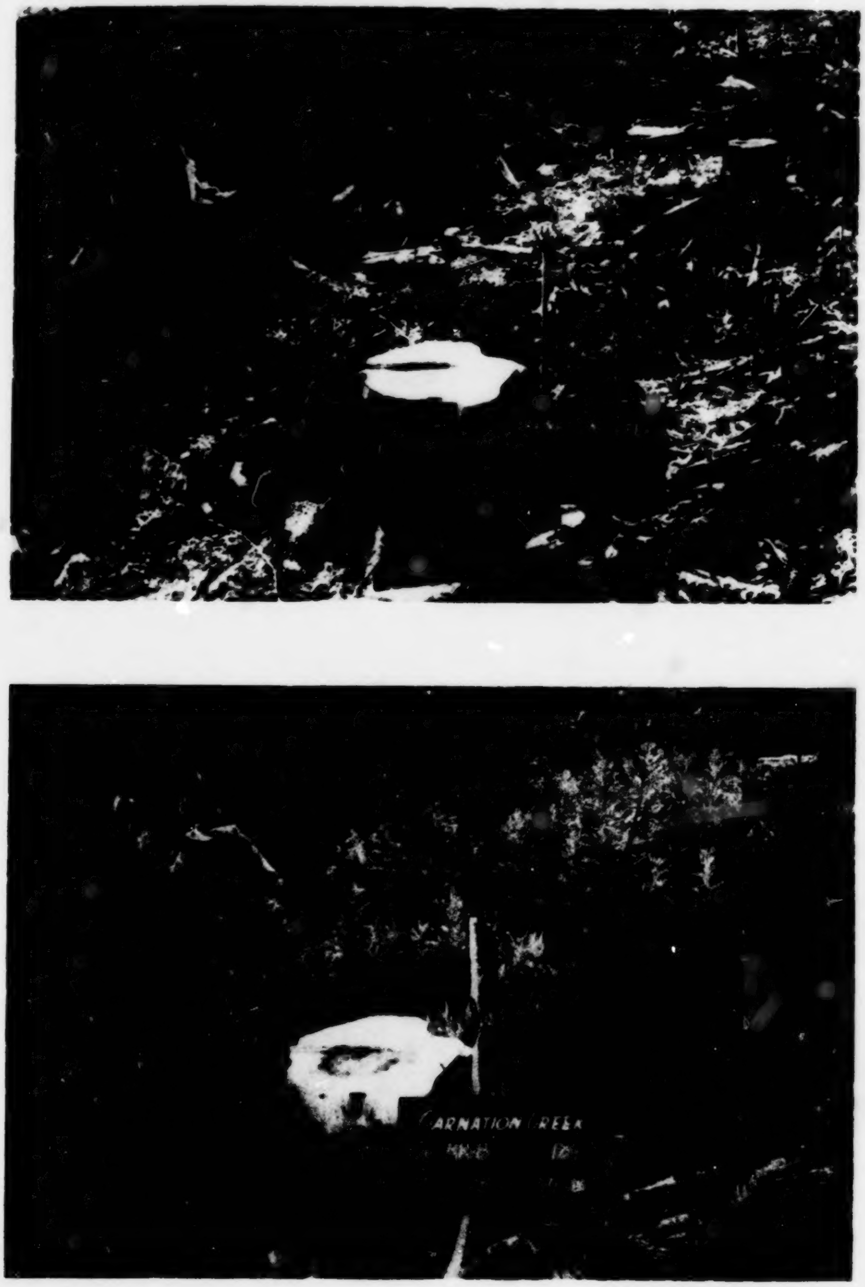


Fig. 6. Middle-slope plot with low intensity burn:

Upper is first-year assessment with 1% shrub cover (mostly of *Gaultheria shallon* and *Vaccinium ovatum*) and 6% forb cover (mostly of *Polystichum munitum* and *Blechnum spicant*).

Lower is third-year assessment with 11% shrub cover (mostly of *Rubus spectabilis* and *Gaultheria shallon*) and 50% forb cover (mostly of *Epilobium angustifolium* and *Blechnum spicant*).

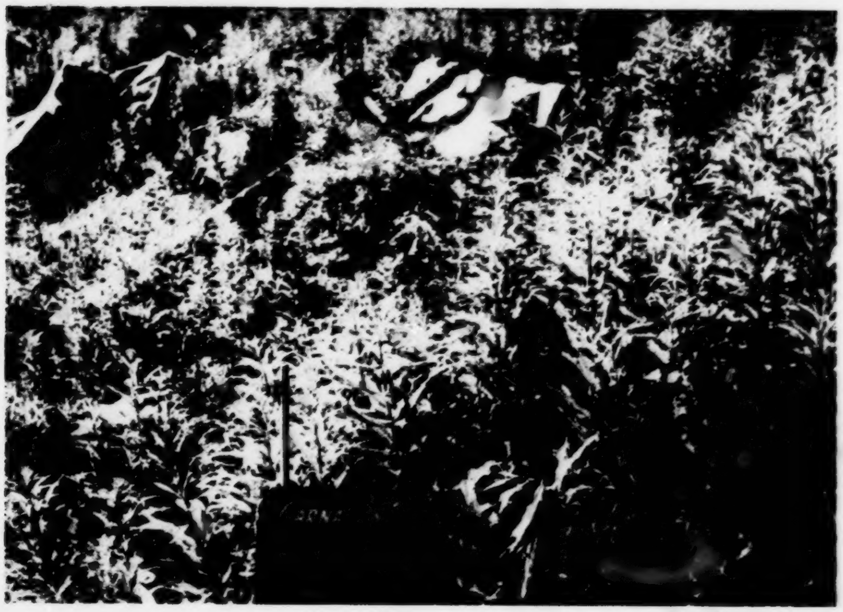


Fig. 7. Upper-slope plot with high intensity burn:

Upper is first-year assessment with 1% forb cover (mostly of *Polystichum munitum*).

Lower is third-year assessment with 14% shrub cover (mostly of *Sambucus racemosa* and *Rubus leucodermis*) and 51% forb cover (mostly of *Epilobium angustifolium* and *Lactuca* spp.).

Table 1. Subunit 1, Floodplain Wetland. Sample size: 7 plots, 28 quadrats. Burn success: 8% of quadrats burned, average intensity low.

	1978			1979			1980		
Tree Species	Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)	
Thuja plicata	32.0	23		17.8	49		17.8	79	
Tsuga heterophylla	7.1	30		0	0		0	0	
Alnus rubra	0	0		3.5	91		7.1	220	
Seedlings, all species	0	0		0	0		3.5	2	
Shrub Species	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***
Rubus spectabilis	57.1	11.9	4	67.8	15.8	5	75.0	26.9	5
Ribes bracteosum	32.1	5.6	5	17.8	4.5	6	17.8	12.6	6
Sambucus racemosa	25.0	1.1	3	32.1	4.4	5	25.0	7.8	6
Gaultheria shallon	17.9	3.3	5	3.5	<1	2	3.5	<1	4
Vaccinium ovalifolium	10.7	<1	4	3.5	<1	2	<1	<1	4
Vaccinium parvifolium	3.5	<1	3	3.5	<1	3	0	0	0
Rubus parviflorus	0	0	0	0	0	0	3.5	<1	5
Rubus leucodermis	0	0	0	0	0	0	3.5	<1	5
Forb and Moss Species	Freq.	% Cover		Freq.	% Cover		Freq.	% Cover	
Polystichum munitum	60.7	11.2		25.0	3.1		53.5	11.7	
Galium boreale	39.3	5.3		60.7	5.6		35.7	2.7	
Tiarella trifoliata	35.7	2.0		24.1	<1		28.5	1.7	
Blechnum spicant	32.1	2.9		53.5	9.7		25.0	3.0	
Grass spp.	21.4	<1		21.4	1.0		28.5	2.2	
Hylocomium splendens	17.9	3.3		0	0		0	0	
Athyrium felix-femina	17.9	1.3		17.8	<1		28.5	4.6	
Maianthemum dilatatum	17.9	1.1		28.5	2.2		17.8	1.5	
Claytonia sibirica	14.3	1.0		3.5	<1		3.5	<1	
Epilobium spp.	17.9	<1		71.4	5.3		35.7	2.6	
Tolmia menziesii	10.7	<1		10.7	<1		10.7	3.9	
Circea alpina	7.1	3.2		14.2	4.1		0	0	
Luzula spp.	7.1	<1		3.5	<1		3.5	<1	
Mitella pentandra	7.1	<1		10.7	<1		3.5	<1	
Viola glabella	3.5	<1		0	0		0	0	

Table 1. *(continued)*

Forb and Moss Species *(continued)*	Freq.	% Cover	Freq.	% Cover	Freq.	% Cover
Adendocaulin bicolor	3.5	< 1	7.1	< 1	0	0
Rhytidiadelphus loreus	3.5	< 1	0	0	0	0
Isothecium spiculiferum	3.5	< 1	0	0	0	0
Oenanthe sarmentosa	3.5	< 1	0	0	3.5	< 1
Lactuca spp.	3.5	< 1	10.7	< 1	10.7	< 1
Lysichiton americanum	3.5	< 1	3.5	< 1	3.5	< 1
Polytrichum juniperinum	0	0	10.7	< 1	0	0
Pteridium aquilinum pubescens	0	0	7.1	1.2	7.1	< 1
Saxifrage spp.	0	0	7.1	< 1	14.2	< 1
Stachys cooleyae	0	0	7.1	< 1	0	0
Senecio spp.	0	0	7.1	< 1	0	0
Tiarella unifoliata	0	0	3.5	< 1	0	0
Streptopus amplexifolius	0	0	3.5	< 1	7.1	1.0
Cirsium lanceolatum	0	0	3.5	< 1	7.1	7.1
Anaphalis margaritacea	0	0	0	0	10.7	< 1
Moss spp.	0	0	0	0	3.5	< 1
Sedge spp.	0	0	0	0	3.5	< 1
Equisetum spp.	0	0	0	0	3.5	< 1

* Percent of quadrats in which the species occurs.

** The averages of the coverages recorded for all quadrats in which the species occurs.

*** Height classes: 1 = 0 to 8 cm, 2 = 9 to 15 cm, 3 = 16 to 30 cm, 4 = 31 to 60 cm, 5 = 61 to 120 cm, 6 = 121 to 200 cm.

Table 2. Subunit 2, Lower Slope. Sample size: 11 plots, 44 quadrats. Burn success: 52% of quadrats burned, average intensity low.

	1978			1979			1980		
Tree Species	Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)	
Tsuga heterophylla	40.9	17		45.4	44		34.0	76	
Taxus brevifolia	2.2	180		2.2	250		2.2	240	
Seedlings, all species	0	0		6.8	2		0	0	
Shrub Species	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***
Gaultheria shallon	47.7	3.8	3	40.9	5.8	3	54.0	12.0	4
Rubus spectabilis	27.2	2.3	3	36.3	7.7	4	54.5	11.8	4
Vaccinium ovalifolium	20.4	1	3	13.6	1.5	4	13.6	2.6	5
Vaccinium ovatum	11.3	2.3	3	4.5	1.3	3	4.5	1.1	6
Vaccinium parvifolium	6.8	< 1	6	13.6	> 1	4	13.6	< 1	5
Sambucus racemosa	2.2	< 1	3	25.0	> 1	4	18.1	< 1	4
Forb and Moss Species	Freq.	% Cover		Freq.	% Cover		Freq.	% Cover	
Blechnum spicant	47.7	7.5		70.4	8.3		68.1	15.8	
Epilobium spp.	13.6	1.6		70.4	5.3		50.0	8.2	
Polystichum munitum	6.8	< 1		13.6	< 1		6.8	< 1	
Tiarella trifoliata	4.5	< 1		9.0	< 1		2.2	< 1	
Hylocomium splendens	2.2	< 1		0	0		0	0	
Lactuca spp.	2.2	< 1		6.8	< 1		9.0	1.1	
Senecio spp.	0	0		25.0	1.2		0	0	
Anaphalis margaritacea	0	0		9.0	< 1		4.5	< 1	
Luzula spp.	0	0		4.5	< 1		4.5	< 1	
Athyrium felix-femina	0	0		4.5	< 1		0	0	
Grass spp.	0	0		2.2	< 1		0	0	
Polytrichum juniperinum	0	0		2.2	< 1		2.2	< 1	
Streptopus amplexifolius	0	0		2.2	< 1		0	0	
Claytonia sibirica	0	0		0	0		2.2	< 1	
Liverwort spp.	0	0		0	0		2.2	< 1	
Cirsium lanceolatum	0	0		0	0		2.2	< 1	

* Percent of quadrats in which the species occurs.

** The averages of the coverages recorded for all quadrats in which the species occurs.

*** Height classes: 1 = 0 to 8 cm, 2 = 9 to 15 cm, 3 = 16 to 30 cm, 4 = 31 to 60 cm, 5 = 61 to 120 cm, 6 = 121 to 200 cm.

Table 3. Subunit 3, Middle Slope. Sample size: 25 plots, 100 quadrats. Burn success: 93% of quadrats burned, average intensity low to moderate.

	1978			1979			1980		
Tree Species	Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)	
Seedlings, all species	6.0	2		2.0	2		14.0	2	
Pseudotsuga menziesii	0	0		44.0	30		30.0	32	
Tsuga heterophylla	0	0		5.0	8		4.0	20	
Abies amabilis	0	0		3.0	30		0	0	
Shrub Species	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***
Gaultheria shallon	60.0	2.2	3	64.0	5.7	3	72.0	15.6	3
Vaccinium ovatum	17.0	< 1	3	16.0	1.5	3	16.0	2.7	3
Rubus spectabilis	6.0	< 1	3	24.0	1.0	3	30.0	2.6	3
Sambucus racemosa	3.0	< 1	2	7.0	< 1	4	3.0	< 1	4
Vaccinium ovalifolium	1.0	< 1	3	0	0	0	0	0	0
Rubus parviflorus	0	0	0	2.0	< 1	4	3.0	< 1	4
Vaccinium parvifolium	0	0	0	1.0	< 1	3	1.0	< 1	3
Forb and Moss Species	Freq.	% Cover		Freq.	% Cover		Freq.	% Cover	
Blechnum spicant	23.0	1.6		33.0	3.5		38.0	7.9	
Epilobium spp.	10.0	< 1		83.0	6.3		77.0	11.8	
Polystichum munitum	5.0	< 1		4.0	< 1		5.0	< 1	
Anaphalis margaritacea	2.0	< 1		9.0	< 1		9.0	< 1	
Pogonatum contortum	1.0	< 1		1.0	< 1		0	0	
Senecio spp.	0	0		77.0	3.4		0	0	
Polytrichum juniperinum	0	0		4.0	< 1		2.0	< 1	
Lactuca spp.	0	0		3.0	< 1		5.0	< 1	
Galium boreale	0	0		1.0	< 1		1.0	< 1	
Cirsium lanceolatum	0	0		1.0	< 1		4.0	< 1	
Claytonia sibirica	0	0		0	0		1.0	< 1	

* Percent of quadrats in which the species occurs.

** The averages of the coverages recorded for all quadrats in which the species occurs.

*** Height classes: 1 = 0 to 8 cm, 2 = 9 to 15 cm, 3 = 16 to 30 cm, 4 = 31 to 60 cm, 5 = 61 to 120 cm, 6 = 121 to 200 cm.

Table 4. Subunit 4, Middle Wetland. Sample size: 4 plots, 16 quadrats. Burn success: 62.5% of quadrats burned, average intensity low.

	1978			1979			1980		
Tree Species	Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)	
Pseudotsuga menziesii	0	0		31.5	27		12.5	34	
Thuja plicata	0	0		6.2	16		12.5	42	
Tsuga heterophylla	0	0		6.2	13		0	0	
Seedlings, all species	0	0		25.0	2		62.5	2	
Shrub Species	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***
Rubus spectabilis	56.2	3.3	4	56.2	5.3	4	62.5	15.6	5
Vaccinium ovalifolium	18.7	<1	3	0	0	0	6.2	<1	4
Gaultheria shallon	12.5	<1	4	43.7	1.3	4	25.0	2.0	4
Sambucus racemosa	0	0	0	6.2	<1	4	0	0	0
Forb and Moss Species	Freq.	% Cover		Freq.	% Cover		Freq.	% Cover	
Blechnum spicant	31.2	<1		62.5	5.5		18.7	4.3	
Polystichum munitum	18.7	1.0		6.2	<1		12.5	3.6	
Tolmia menziesii	12.5	<1		0	0		0	0	
Tiarella trifoliata	12.5	<1		6.2	<1		12.5	<1	
Galium boreale	6.2	<1		18.7	1.4		25.0	<1	
Epilobium spp.	0	0		62.5	2.3		56.2	9.8	
Senecio spp.	0	0		25.0	<1		0	0	
Saxifrage spp.	0	0		18.7	<1		18.7	3.5	
Grass spp.	0	0		12.5	<1		0	0	
Polytrichum juniperinum	0	0		12.5	<1		0	0	
Lactuca spp.	0	0		12.5	<1		12.5	<1	
Sedge spp.	0	0		6.2	<1		0	0	
Pogonatum contortum	0	0		6.2	<1		0	0	
Anaphalis margaritacea	0	0		6.2	<1		12.5	<1	
Lysichiton americanum	0	0		6.2	<1		0	0	
Mitella pentandra	0	0		6.2	<1		0	0	
Luzula spp.	0	0		0	0		25.0	2.9	

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* Percent of quadrats in which the species occurs.

** The averages of the coverages recorded for all quadrats in which the species occurs.

*** Height classes: 1 = 0 to 8 cm, 2 = 9 to 15 cm, 3 = 16 to 30 cm, 4 = 31 to 60 cm, 5 = 61 to 120 cm, 6 = 121 to 200 cm.

Table 5. Subunit 5, Upper Slope. Sample size: 10 plots, 40 quadrats. Burn success: 87.5% of quadrats burned, average intensity moderate to high.

	1978			1979			1980		
Tree Species	Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)		Freq.*	Avg. Ht. (cm)	
Pseudotsuga menziesii	0	0		62.5	28		45.0	27	
Seedlings, all species	0	0		0	0		32.5	2	
Shrub Species	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***	Freq.	% Cover**	Ht. Class***
Gaultheria shallon	20.0	<1	3	32.5	3.7	3	42.5	10.9	3
Vaccinium parvifolium	2.5	<1	3	2.5	<1	3	5.0	<1	3
Rubus spectabilis	0	0	0	10.0	<1	3	12.5	<1	3
Rubus leucodermis	0	0	0	7.5	<1	3	7.5	<1	3
Sambucus racemosa	0	0	0	5.0	<1	2	2.5	<1	3
Vaccinium ovatum	0	0	0	2.5	<1	3	5.0	<1	3
Rubus parviflorus	0	0	0	2.5	<1	3	2.5	<1	3
Vaccinium ovalifolium	0	0	0	0	0	0	2.5	<1	3
Forb and Moss Species	Freq.	% Cover		Freq.	% Cover		Freq.	% Cover	
Epilobium spp.	15.0	<1		85.0	11.9		80.0	24.6	
Polystichum munitum	2.5	<1		15.0	<1		7.5	<1	
Anaphalis margaritacea	2.5	<1		7.5	<1		10.0	<1	
Senecio spp.	0	0		70.0	4.0		2.5	<1	
Blechnum spicant	0	0		10.0	<1		15.0	<1	
Lactuca spp.	0	0		5.0	<1		12.5	<1	
Galium boreale	0	0		2.5	<1		0	0	
Luzula spp.	0	0		2.5	<1		0	0	
Polytrichum juniperinum	0	0		0	0		7.5	2.6	
Mitella pentandra	0	0		0	0		2.5	<1	
Cirsium lanceolatum	0	0		0	0		2.5	<1	

* Percent of quadrats in which the species occurs.

** The averages of the coverages recorded for all quadrats in which the species occurs.

*** Height classes: 1 = 0 to 8 cm, 2 = 9 to 15 cm, 3 = 16 to 30 cm, 4 = 31 to 60 cm, 5 = 61 to 120 cm, 6 = 121 to 200 cm.

APPENDIX

LIST OF PLANT NAMES

Trees

Abies amabilis	Amabilis fir
Alnus rubra	Red alder
Pseudotsuga menziesii	Douglas-fir
Taxus brevifolia	Western yew
Thuja plicata	Western red cedar
Tsuga heterophylla	Western hemlock

Shrubs

Gaultheria shallon	Salal
Ribes bracteosum	Stink current
Rubus leucodermis	Black raspberry
Rubus parviflorus	Thimbleberry
Rubus spectabilis	Salmonberry
Sambucus racemosa	Red elderberry
Vaccinium ovalifolium	Tall huckleberry
Vaccinium ovatum	Evergreen huckleberry
Vaccinium parvifolium	Red huckleberry

Forbs

Adendocaulin bicolor	Silvergreen
Anaphalis margaritacea	Pearly everlasting
Athyrium felix-femina	Lady fern
Blechnum spicant	Deer fern
Circea alpina	Enchanted nightshade
Cirsium lanceolatum	Bull thistle
Claytonia sibirica	Siberian spring beauty
Galium boreale	Northern bedstraw
Luzula parviflora	Wood-rush
Lysichiton americanum	Skunk cabbage
Maianthemum dilatatum	False lily-of-the-valley
Mitella pentandra	Five-stamened mitrewort
Oenanthe sarmentosa	Wild parsley
Polystichum munitum	Sword fern
Pteridium aquilinum pubescens	Bracken fern
Stachys cooleyae	Hedge nettle
Streptopus amplexifolius	Twisted stalk
Tiarella trifoliata	Trifoliate-leaved foamflower
Tiarella unifoliata	Unifoliate-leaved foamflower
Tolmia menziesii	Youth-on-age
Viola glabella	Violet

THE EFFECTS OF THREE STREAMSIDE LOGGING TREATMENTS ON ORGANIC DEBRIS AND CHANNEL MORPHOLOGY OF CARNATION CREEK

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INTRODUCTION

A striking feature of the small streams of the overmature west coast forest is the number of trees, log chunks, branches, and root wads that accumulate naturally in the stream channel. This debris is deposited in the channel by natural processes and remains part of the stream for many years (Swanson, Lienkaemper, and Sedell 1976).

Numerous studies have documented the importance of this large organic debris as a determinant of channel form in small- and intermediate-sized streams and as an extremely important component of fish habitat. The large organic debris reduces stream velocity, dissipates stream energy, and alows the movement of gravel and organic material through the stream system (Heede 1972; Swanson, Lienkaemper, and Sedell 1976; Megahan 1982). Large stable debris creates pools, back eddies, small falls, and many of the hiding and resting places which are desirable components of fish habitat (Hall and Baker 1975). Debris separates a stream reach into distinct pool and riffle sequences and separates habitat into discrete units. Both young and adult salmon use debris accumulations as cover, and overwintering coho and steelhead fry are most commonly found associated with upturned root wads and logs (Bustard and Narver 1975; Hartman 1965). Natural debris in the stream also provides habitat and food for numerous aquatic organisms which are important parts of the food chain in the stream (Sedell and Triska 1977). A detailed review of the biological role of debris is provided by Hall and Baker (1975), whereas Keller and Tally (1979) provide a detailed discussion of the influence of debris on physical stream processes.

Streamside logging activities can alter the amount and distribution of debris in the stream in several ways (Froehlich 1975; Lammell 1972; Meehan et al. 1969; McGreer 1974; Swanson, Lienkaemper, and Bryant 1981; Toews and Moore 1982). Falling of streamside trees can introduce large volumes of large debris into the stream channel and can break existing large natural debris into smaller pieces. Bucking and limbing of trees introduces tops and limbs to the stream channel. Yarding activities generally remove any large pieces introduced in falling, but leave the tops and limbs and broken pieces of nonmerchantable logs. Yarding can also remove existing natural debris or break it into small pieces. It can also drag additional tops and limbs from the streamside into the stream channel. In general, studies have indicated that the net result of these logging activities is a lower volume of debris in the stream channel but a greater number of pieces of small size (Toews and Moore 1982). Results of studies, however, have been variable and appear to be dependent on the specific falling and yarding techniques used.

One of the original objectives of the Carnation Creek project was to incorporate a range of streamside logging treatments in order to compare the impact of different logging methods on various stream parameters. In an earlier paper (Toews and Moore 1982), the impact of one intense logging treatment on the stability and distribution of large organic debris in three reaches of Carnation Creek was documented. In this paper, the impacts of three (rather than one) streamside logging treatments are evaluated. In addition to evaluating changes in large organic debris, changes in volumes of small organic debris, in streambed topography, and in rates of streambank erosion are evaluated.

Table 1. Streamside logging treatments in Carnation Creek.

Treatment	Description	Study Reach	Date of Logging
1. Leave-Strip Treatment	Merchantable trees left along both sides of the stream in widths varying from 1 m to 70 m.	II, III, and IV	1978-1979[*]
2. Careful Treatment	All merchantable timber felled but nonmerchantable trees, alder, and deciduous vegetation left. Trees felled and yarded away from the stream channel. After logging, seed alder was removed.	VIII	1978-1979
3. Intense Treatment	All trees including nonmerchantable trees and alder were felled along the streamside. Leaners and snags were felled across the channel and yarded out.	V, VI, and VII	1976-1977

[*] An area on the north side of the stream adjacent to reaches II and III was logged in 1975-1976. However, a wide leave strip was left. For purposes of analysis, the year of logging is considered to be 1978-1979 when the area adjacent to the south bank reaches II, III, and IV was logged leaving a narrow leave strip.

METHODS

Description of Streamside Logging Treatments

The experimental design for Carnation Creek includes a number of clearcuts and a range of logging treatments along the streamside. A complete description of the logging operations is outlined in the preceding paper by Dryburgh. The three streamside treatments that are compared in this paper are as shown in Table 1.

In all treatments, falling was conventional chainsaw falling. Directional falling equipment such as cables and jacks were used in selected areas, and all trees were limbed and bucked to length. Yarding was conventional high-lead yarding. None of the streamside areas were slash burned.

Treatment 1 provided a leave strip on both sides of the stream. On the south side, the strip included mature standing trees and was generally less than 5 m wide. On the north side of the stream, a strip of variable width was left, ranging from a single tree up to an unlogged block of timber; but this strip was generally wider than that left on the south side.

Treatment 2, the careful treatment, included logging on both sides of the stream during the same year. All merchantable trees were felled and yarded away from the stream with care. Deciduous and nonmerchantable trees were left standing during logging, but seed alder trees were subsequently felled. This treatment was similar to the normal streamside treatment to the extent that the objective was to avoid any activity in the stream channel. No debris was to be added to, or removed from, the stream channel. Following prelogging field consultations, a few trees that could not be removed within the above constraints were felled across the stream channel and yarded out.

In Treatment 3, the intense treatment, fallers were directed to fall trees away from the stream, where possible, but approximately 25 leaning trees and snags were felled into or across the stream. All alder trees along the streamside were also felled and many of them fell into the stream channel. These alder had been killed the previous year using "hack and squirt" techniques. Landings were established on both sides of the stream and, wherever possible, logs were yarded away from or out of the channel. All merchantable material was removed from the stream channel, but there was no attempt to remove nonmerchantable slash from the stream during or after logging. This treatment is more extreme than the normal practices presently allowed by the Ministry of Forests and the fisheries agencies, and the normal stream protection (P) clauses were waived.

Description of Study Reaches

Nine representative study reaches varying between 50 m and 75 m length were established during the prelogging phase of the project and were the sites of detailed studies, including mapping and measurement of large organic debris. Seven of these reaches, II to VIII, were within the area logged between 1975 and 1979, using the different streamside treatments. Each of these reaches is within the area utilized by anadromous fish and has been surveyed and mapped annually since 1973. Figure 1 shows the location of these study reaches and the logging adjacent to them. Figure 2 shows examples of the debris maps that were prepared annually for each study reach.

Debris and Channel Mapping and Measurement

Standard survey methods were used to accurately locate pieces of debris with reference to numbered points located every 3 m on both sides of the stream in each study reach. A theodolite (1 minute accuracy), chains, and level rods were used as equipment. The length of each piece of debris was measured as a check on triangulation. Diameters of each end of each piece were measured in the field, and length, diameters, and comments regarding changes in the stream or pieces of debris were recorded in field notebooks. All surveying and measurements were done between May 30 and July 20 each year.

Maps of each study reach were prepared annually from the field notes using standard plotting methods (Davis and Foote 1953). Any changes to the maps from the previous year which appeared to be questionable were checked in the field notebook and in the field, if necessary. The volumes of debris in each reach were computed annually from measurements made on maps. Individual piece volumes were similarly measured.

Only pieces of debris 3 m in length or longer were mapped. These are referred to as large organic debris. Individual pieces in each reach were numbered on the maps to record annual changes and a debris budget prepared showing the number of pieces which moved into, moved out of, and remained in place in each reach each year.

The total volume of large organic debris in each study reach was estimated from the debris maps[1]. Each piece of large debris was approximated to a cylinder with dimensions measured from the maps, and individual piece volumes were calculated. Inconsistencies in debris measurements were clarified by reference to the original field survey notes. Since study reaches were of different lengths, total volumes were calculated and then reported as cubic metres per 30 m of reach length ($m^3/30$ m) for comparative purposes.

The volumes of piles of small organic debris that accumulated following logging were estimated in 1981. Field measurements were made of the volume of debris piles and an estimate was made of the percentage of that volume that was small debris (since piles included both large and small debris). The volumes were further reduced to account for void space.

Large-scale air photos flown in 1979 were then used to provide an estimate of the volume of small organic debris piles two years earlier. Piles were mapped from the photos at an approximate scale of 1:1600 and surface area was measured from the photos. Volume was calculated by estimating the mean depth of the pile and was reduced to account for void space and

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[1] The debris volume data in this report, including both large organic debris and small organic debris piles, were compiled by Schultz International Ltd. under a contract with Department of Fisheries and Oceans. Results are reported in Schultz International (1981), "An Analysis and Summary of Data on Changes in Debris and Channel Morphology in Carnation Creek, 1971-1980". Discrepancies in total debris volumes for reaches IV, V, VI, VII, and VIII between the Schultz report (as reported here) and those reported by Toews and Moore (1982) arise because Toews and Moore (1982) calculated debris volumes directly from the field notes while Schultz estimated debris volumes from measurements off the maps.

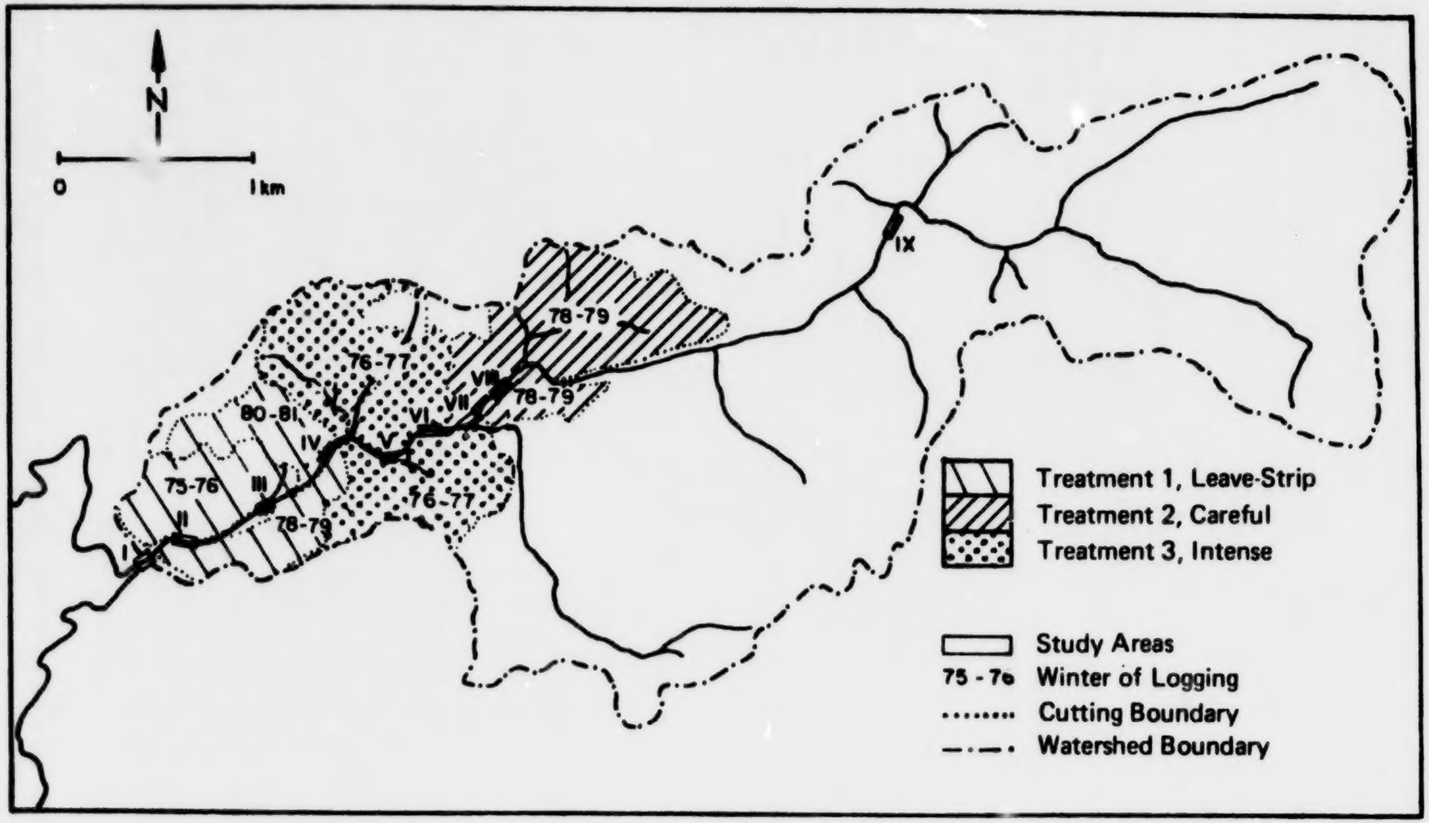
N
0
1km
I
II
III
IV
V
VI
VII
VIII
IX
75-76
80-81
76-77
76-77
78-79
78-79
78-79
Treatment 1, Leave-Strip
Treatment 2, Careful
Treatment 3, Intense
Study Areas
75 - 76 Winter of Logging
Cutting Boundary
Watershed Boundary

Fig. 1. A map of the Carnation Creek watershed indicating the locations of study reaches and logging treatments.

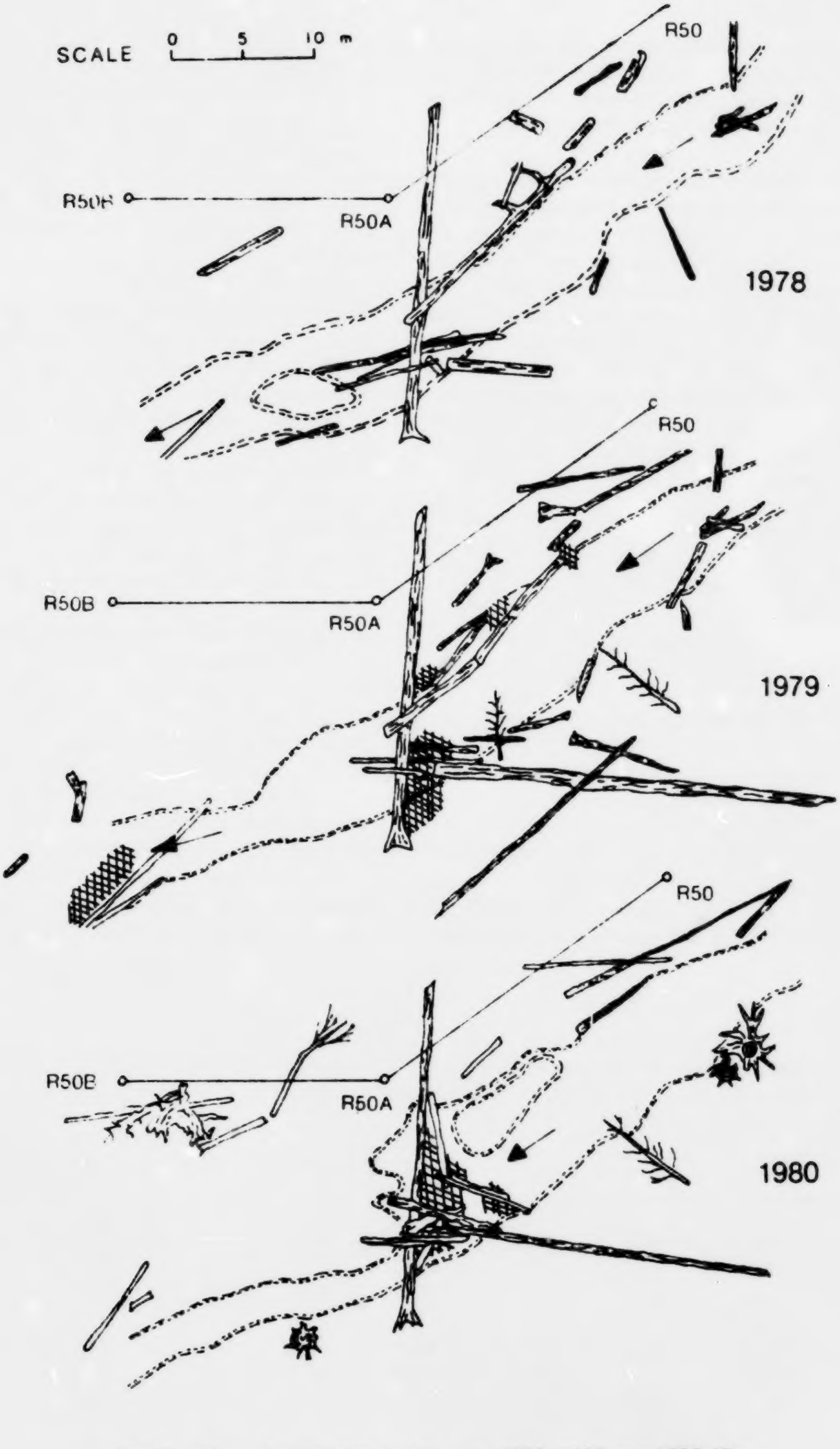
SCALE
0
5
10 m
R50
R50B
R50A
1978
R50
R50B
R50A
1979
R50
R50B
R50A
1980

Fig. 2. Maps of reach VIII for the years 1978, 1979, and 1980. The cross-hatched areas on the 1979 and 1980 maps indicate accumulations of fine debris. Logging took place in 1978 and 1979 between the preparation of the maps for those years.

large organic debris in the pile. Data derived in this way is approximate, due to the limited resolution of the air photos and the broad assumptions made.

During the annual summertime survey of the study reaches, cross-sectional profiles were surveyed with reference to pairs of hubs on opposite banks of the channel. This survey data was used to prepare contour maps of the streambed for the years 1973, 1976, and 1979 and to draw longitudinal profiles of the streambed on an annual basis. Examples of these contour maps and longitudinal profiles are shown in Figures 4 and 5. The cross-sectional profile data were also used to provide estimates of streambank erosion for the periods 1973 to 1976 and 1976 to 1979.

RESULTS

Changes in Large Organic Debris

Changes in Stability of Large Debris

Stability indices for each of the seven study reaches II to VIII for the seven years before and after logging are shown in Table 2. These stability indices are the percentage of pieces in a study reach that remain from the total number in that reach the previous year. In all study reaches, there is variation in the indices before logging. For example, in study reach II, the stability index ranged from 32.4 to 69.2, and in study reach III, the values ranged from 20.8 to 96.0. The other five study reaches were generally more stable and showed less variation. It is evident from these indices and from comparison of the maps (Fig. 2) that the stream reaches are dynamic with pieces of debris moving in and out of each reach each year.

The changes in stability in each reach following logging are shown in Table 3 by comparing the means of the stability indices for the periods before and after logging. From these tables, the effects of each of the three streamside logging treatments can be seen.

The leave-strip treatment, Treatment 1, did not result in a significant change in the indices of stability in any of the three reaches affected by this treatment. Two of these reaches (II and III) showed considerable variation prior to logging and, in fact, the mean index of stability in these reaches increased following logging. The increase in the mean index of stability in reach IV is not significant (t-test, $P < 0.05$).

The effects of the intense logging treatment, Treatment 3, are reported in detail in Toews and Moore (1982) and the reader is referred to that report for a complete presentation of the results of this streamside logging treatment. It led to a significant reduction in the indices of stability, compared to the prelogging period in the same reaches. Mean indices of stability were reduced from 80.2, 93.1, and 98.9

Table 2. Stability indices (i.e., the percentage of pieces remaining from the previous year) for the seven study reaches for the period 1974 to 1980. The stippled area indicates the period after logging.

Reach	1974	1975	1976	1977	1978	1979	1980	Treatment
II	58.7	64.5	32.4	69.2	48.6	78.1	48.6	1. Leave-Strip
III	64.0	20.8	26.5	96.0	57.7	66.7	56.7	"
IV	94.4	91.7	76.5	100.0	59.5	87.7	54.8	"
V	81.8	100.0	58.8	26.7	28.8	54.3	33.3	3. Intense
VI	91.7	91.3	96.2	33.3	47.4	47.2	47.8	"
VII	100.0	100.0	96.6	65.5	66.7	44.4	48.4	"
VIII	66.7	94.1	80.0	90.5	80.0	50.0	28.0	2. Careful

Table 3. Means of stability indices for each study reach before and after logging.

Reach	Before Logging	After Logging	Treatment
II	54.7	63.3	1. Leave-Strip
III	53.0	61.7	"
IV	84.4	61.2	"
V	80.2	35.7*	3. Intense
VI	93.1	43.9*	"
VII	98.9	56.2*	"
VIII	82.3	39.0*	2. Careful

* Significantly different than prior to logging (t-test, $P < 0.05$).

to 35.7, 43.9, and 56.2 in reaches V, VI, and VII respectively. Each of these changes is significant (t-test, $P < 0.05$).

This reduction in the stability of debris following logging was caused primarily by the increase in the number of pieces added to the stream by falling and yarding and by the greater mobility of this introduced debris. Additionally, falling into the stream broke up a number of large, old pieces of debris and several old pieces were removed by yarding.

The careful logging treatment, Treatment 2, also led to a significant reduction in the index of stability for the reach affected by this treatment. The prelogging mean index of stability of 82.3 fell to 39.0 and this change is also significant (t-test, $P < 0.05$). The reduction in the stability of debris in this reach was

Table 4. The total number of pieces of large organic debris in reaches II to VIII between 1973 and 1980. The stippled area indicates the period after logging.

Reach	1973	1974	1975	1976	1977	1978	1979	1980	Treatment
II	46	31	34	26	35	32	37	36	1. Leave-Strip
III	25	24	34	25	26	30	30	24	"
IV	18	24	34	38	42	36	31	29	"
V	11	14	17	15	28	35	36	17	3. Intense
VI	24	23	26	27	38	36	23	13	"
VII	21	22	29	29	42	45	31	27	"
VIII	21	17	20	21	20	20	25	21	2. Careful

also due to the addition of debris during logging and its subsequent movement.

Changes in Number of Pieces of Large Debris

Table 4 shows the number of pieces of large debris that were present in each study reach each year and Table 5 presents the means before and after logging.

The leave-strip treatment did not result in any significant changes in the number of pieces of large debris. In each of the three reaches affected by this treatment, the number of pieces following logging was within the range of the prelogging period. Changes in the mean number of pieces before and after logging are not significant in any of these reaches (t-test, $P < 0.05$).

The intense logging treatment did result in a large increase in number of pieces, particularly in the first two years following logging. The earlier report on this intense treatment (Toews and Moore 1982) presents further analysis on this change in number of pieces of debris and shows that these changes are significant (t-test, $P < 0.05$). Analysis of the maps and the debris budgets for each reach indicated that the number of pieces increased dramatically following logging but these pieces were very mobile and quickly moved out of the reach to accumulate in jams. Thus, the number of pieces declined after an initial peak to levels within the range of the prelogging period. In reach V, the mean number of pieces after logging is significantly different (t-test, $P < 0.05$), but in the other two reaches, it is not significantly different, despite the large initial increase.

The careful logging treatment resulted in a similar increase immediately after logging and then a similar decline in the following year. However, the means before and after logging in reach VIII are not significantly different (t-test, $P < 0.05$).

Changes in Volume of Large Debris

Table 6 shows the volume of debris in each study reach in each year before and after logging. For the purposes of this report, this volume is reported as cubic metres per 30 m of stream. It is evident that, under natural prelogging conditions, the volumes of large debris also vary from year to year and are variable from reach to reach, reflecting the dynamic and variable nature of the stream channel.

The effect of the three streamside logging treatments can be seen in Table 6 and in Table 7, which show the mean volumes before and after logging in each study reach. Treatment 1, the leave-strip treatment, did not result in a significant change in the debris volume following logging in any of the three stream reaches subject to this treatment. During the year prior to logging, a very large spruce tree blew down into the stream channel in reach III and caused the increase

Table 5. Mean number of pieces in each reach before and after logging.

Reach	Before Logging	After Logging	Treatment
II	34.0	36.5	1. Leave-Strip
III	27.3	27.0	"
IV	32.0	30.0	"
V	14.2	29.0*	3. Intense
VI	25.0	27.5	"
VII	25.3	36.2	"
VIII	19.8	23.0	2. Careful

* Significantly different than prior to logging (t-test, $P < 0.05$).

Table 6. The total volume of debris (m^3/30 m of study reach) within the stream channel in each study reach. The stippled area indicates the period after logging.

Reach	1973	1974	1975	1976	1977	1978	1979	1980	Treatment
II	31.1	24.2	27.0	28.3	31.2	35.6	32.7	26.2	1. Leave-Strip
III	26.4	26.4	35.0	29.0	29.3	59.0	50.7	50.1	"
IV	25.7	28.9	35.2	45.3	46.1	43.4	41.3	31.5	"
V	24.2	25.3	25.5	26.5	21.3	21.5	26.3	23.7	3. Intense
VI	26.0	25.8	26.1	26.3	23.0	21.7	19.7	15.6	"
VII	77.0	77.3	79.2	79.1	21.1	22.8	19.1	14.8	"
VIII	13.2	13.8	14.5	14.5	14.2	15.6	17.5	11.9	2. Careful

in volume in 1978. The change following logging was not significant (t-test, $P < 0.05$).

The intense logging treatment, Treatment 3, resulted in a decrease in volume in all three study reaches affected by this treatment. Volumes were reduced to levels which were below the volume in the years prior to logging, and for reaches VI and VII, this reduction is significant (t-test, $P < 0.05$). The intense logging treatment resulted in an increase in the number of pieces of debris in the study reach, but these pieces were generally of smaller size. This increase in volume was more than offset by the removal of a number of old pieces of debris of large volume, as is very evident in reach VII.

In all three reaches, the net result is a lower volume of debris. These changes in debris volume character-

Table 7. Mean volume in each study reach in the period before and after logging.

Reach	Before Logging	After Logging	Treatment
II	29.6	29.5	1. Leave-Strip
III	34.2	50.4	"
IV	37.4	36.4	"
V	25.4	23.2	3. Intense
VI	26.0	20.0*	"
VII	78.2	19.5*	"
VIII	14.3	14.7	2. Careful

* Significantly different than prior to logging (t-test, $P < 0.05$).

istics following the intense logging treatment a examined in more detail in Toews and Moore (198 and can be seen on the maps in Figure 2.

The careful treatment in reach VIII resulted in an initial increase in the volume of debris after logging, but this decreased to less than prelogging levels in the second year following harvesting. The change in the mean volumes before and after logging is not significant (t-test, $P < 0.05$). Logging debris introduced by this careful treatment was primarily small and mobile and no large logs were removed. Hence, the stability of debris changed significantly but the volume did not.

Changes in Small Organic Debris

Small organic debris (pieces less than 3 m in length) was not mapped consistently or measured in the prelogging phase of the Carnation Creek study. Thus, it is not possible to provide results on changes in small organic debris over time or to compare prelogging and postlogging distribution of small debris. Following logging of reaches V, VI, and VII, it was observed that this intensive treatment had introduced a considerable amount of small debris to the stream channel. Subsequently, field estimates were made of the volumes of small debris piles in 1981 and were compared with estimates made from air photos taken in 1979. This work was undertaken by Schultz International under the contract referred to earlier. Results are reported in Schultz International Ltd. (1981).

The volume of the debris piles decreased significantly to approximately one tenth of their 1979 size in 1981. High flows during the two intervening winters apparently moved much of the small debris downstream, and changes in the location of debris piles are evident on the maps of 1979 and 1981.

The number and the volumes of the piles of small debris were highest in the intense treatment area (Treatment 3) and these were also the most mobile. Figure 3 shows the distribution of piles of small debris in relation to treatment areas for both 1979 and 1981. The concentrations of small debris between reaches IV and V and in the vicinity of reach VI are evident on this map and also in the photographic record of these reaches. By 1981, much of the small debris had moved downstream and was in piles between study reaches IV and V.

The careful logging treatment (Treatment 2) also resulted in the introduction of small organic debris. This is evident in Figure 3 and also in the large organic debris maps shown in Figure 2.

The introduction of this small organic debris and the subsequent movement and accumulation in jams was

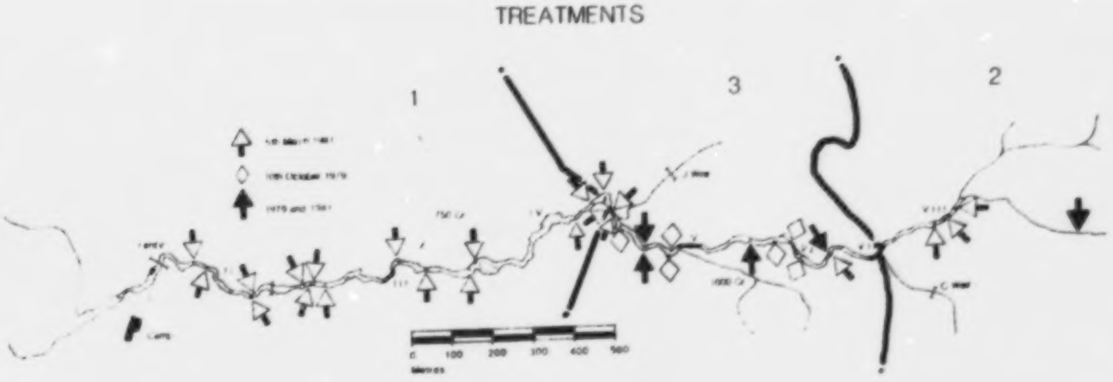

Fig. 3. Map showing piles of small organic debris as they occurred in 1979 (mapped from air photographs) and in 1981 (mapped in the field). Note that only the area above reach IV was mapped in 1979. Locations of debris piles present during both surveys are indicated.

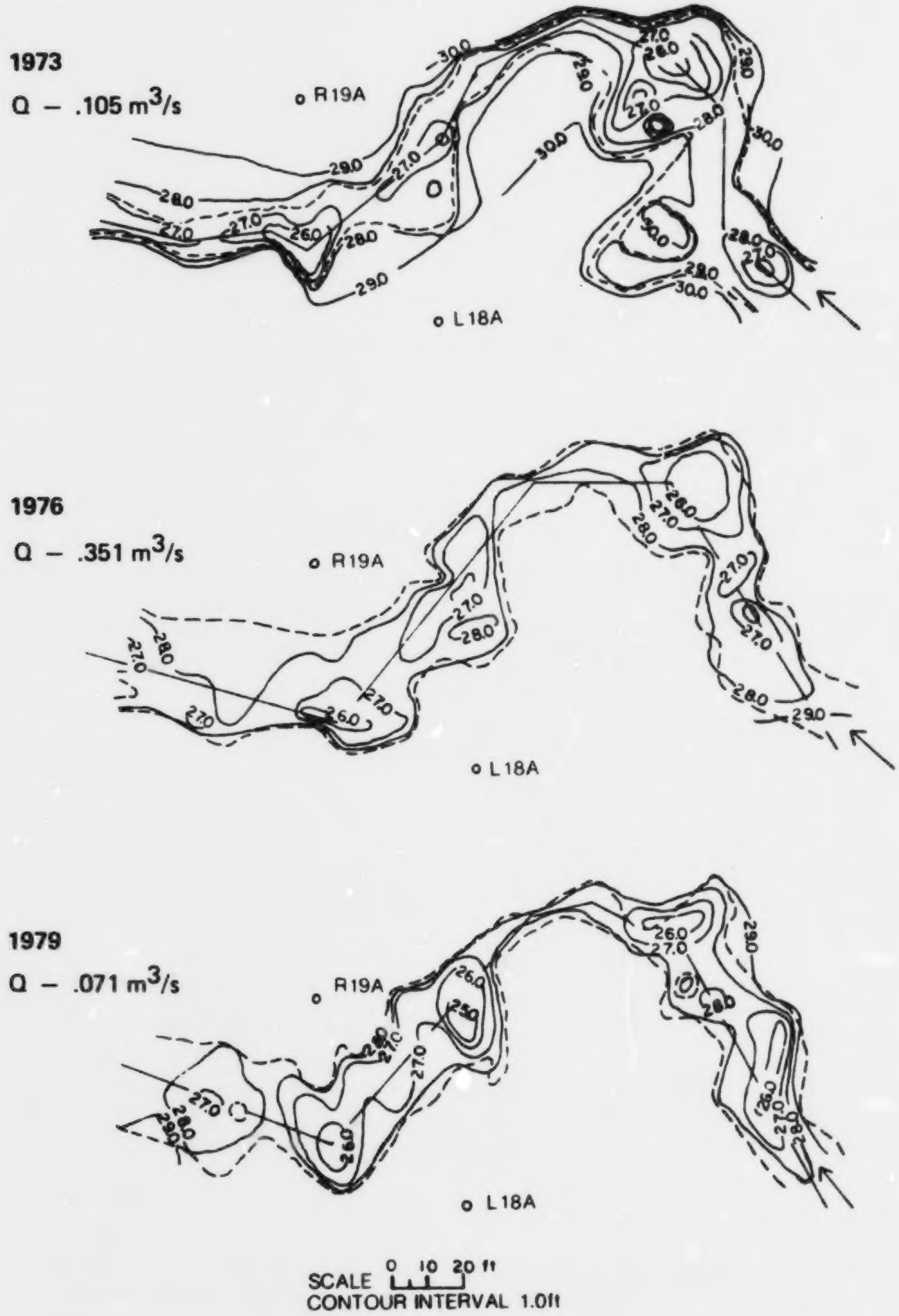
1973
Q – .105 m³/s
R19A
L18A
30.0
29.0
28.0
27.0
26.0
1976
Q – .351 m³/s
R19A
L18A
29.0
28.0
27.0
26.0
1979
Q – .071 m³/s
R19A
L18A
29.0
28.0
27.0
26.0
25.0
SCALE 0 10 20 ft
CONTOUR INTERVAL 1.0ft

Fig. 4. Contour maps of the streambed in study reach III within the leave-strip treatment (Treatment 1). Note that the major pools remain in the same place although the channel changes considerably in the three-year intervals. English units are retained in Figures 4 to 9 because the survey data was collected and mapped in these units.

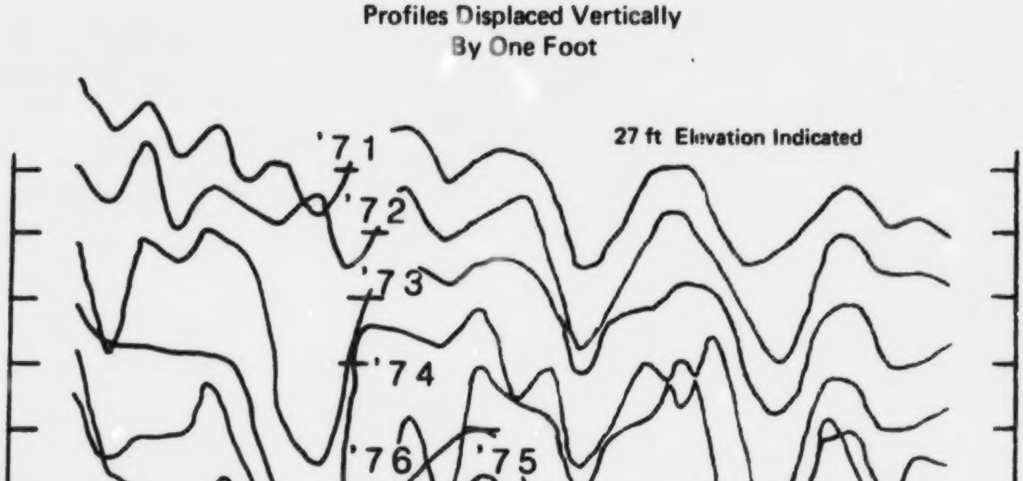

Fig. 5. Longitudinal profiles of the streambed in study reach III between 1971 and 1980. Study reach III is within the leave-strip treatment.

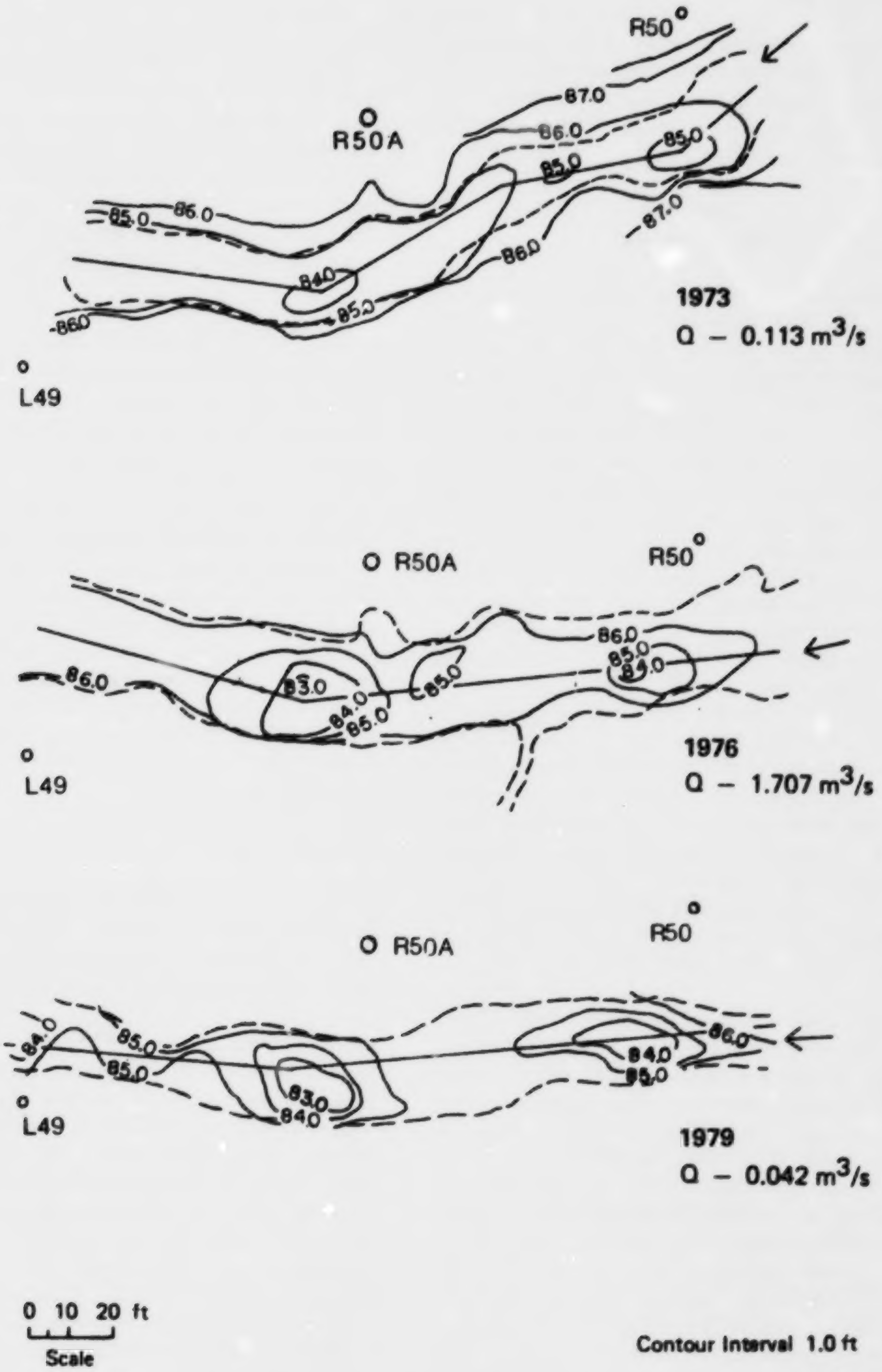
R50
R50A
87.0
86.0
85.0
85.0
86.0
84.0
85.0
86.0
87.0
L49
1973
Q – 0.113 m³/s
R50A
R50
86.0
85.0
84.0
86.0
83.0
85.0
84.0
85.0
L49
1976
Q – 1.707 m³/s
R50A
R50
84.0
85.0
85.0
83.0
84.0
86.0
84.0
85.0
L49
1979
Q – 0.042 m³/s
0 10 20 ft
Scale
Contour Interval 1.0 ft

Fig. 6. Contour maps of the streambed in study reach VIII within the careful treatment (Treatment 2). Note the major pools remain approximately the same.

a particularly important result of the intense and careful logging treatments because much of the streambank erosion that will be reported later in this paper appears to be the result of stream-channel changes which were caused by jams of small debris.

Changes in Channel Topography

The topography of the stream channel is compared before and after logging for the three streamside treatments using contour maps and longitudinal profiles of the study reaches. The nature of these data does not allow for a quantitive comparison with statistical testing similar to that undertaken for large organic debris. Nevertheless, these data have been examined to determine whether there were changes that occurred subsequent to the logging treatment. It should be noted that changes in large and small organic debris can occur immediately and directly as a result of the logging treatment, whereas channel changes that result from altered debris configurations may take several years to develop. This is primarily because high streamflows are necessary to cause the actual changes. The complete data are included in a report compiled by Schultz International Ltd. (1981). However, in this paper, only data representative of the changes that occurred will be presented. Maps and profile diagrams from one of the study reaches in each of the three treatments are presented as Figures 4, 5, 6, 7, 8, and 9. Contour maps for the years 1973, 1976, and 1979 are presented to allow a comparison before logging (1973 versus 1976) and following logging (1976 versus 1979).

The study reaches in the leave-strip treatment (Treatment 1) showed considerable annual variation prior to logging, without any obvious changes attributable to logging or debris alterations. The streambed contour maps for study reach III are depicted in Figure 4. Localized shifting of the bed is evident on an annual basis; however, the locations of the major pools remained the same between 1973 and 1979. The longitudinal profiles depicted in Figure 5, a pool became evident in the vicinity of cross section 8 in 1973, reached a maximum depth in 1974, and thereafter maintained its location, but varied in depth. Considerable variation was evident between cross sections 15 and 20 during the period 1972 and 1980. Study reach III showed considerable instability in the natural state with no obvious changes following logging. A large Sitka spruce tree fell across the study area in the winter of 1977-1978, causing some localized streambed shifting, particularly between cross sections 1 and 5. Maps and longitudinal profiles, similar to those depicted in Figures 4 and 5, were prepared and examined for study reaches II and IV (Schultz International Ltd. 1981), which were also logged with the leave-strip treatment. The pool locations remained relatively stable, although there appeared to be considerable lateral shifting of pools in study reach II. This lateral shifting likely accounted for considerable annual variations in longitudinal profiles in study reach II.

In summary, these three study reaches within the area bounded by leave strips (Treatment 1) showed considerable variation in their natural state. Changes associated with logging or additions of debris associated with logging are not evident.

Changes in the careful treatment (Treatment 2) are examined by analyzing changes in study reach VIII. The streambed contour maps for study reach VIII are depicted in Figure 6. The locations of the pools are similar throughout the time period 1973 to 1979, although the depths of the pools and the contours vary. The longitudinal profiles (Fig. 7) remained relatively uniform between 1971 and 1979, with a gradual deepening of pools at cross sections 4 and 12. Some annual variation was evident between cross sections 14 and 18.

Following logging, the buildup of a jam of small organic debris is evident in the vicinity of cross section 11 and was likely responsible for the profile changes in 1980. As reported earlier, the accumulation of small organic debris is evident by contrasting debris maps of reach VIII in 1978 and 1980 (Fig. 2).

Changes in the streambed topography of the reaches logged with the intense treatment were examined by analyzing changes in the contour maps and longitudinal profiles of reaches V, VI, and VII. The most apparent changes took place in study reach VI and these changes are depicted in Figure 8. Several pools are evident in the 1973 and 1976 maps depicting conditions before logging. In 1979, the pools had disappeared and the contours were more or less parallel to the channel banks. These changes are also evident in the longitudinal profiles provided in Figure 9. Several pools were evident between 1971 and 1978. Major changes took place in 1979 and 1980 after logging. Similar contour changes were not evident in the bed contour maps of study reaches V and VII. Longitudinal profile diagrams of study reach V showed some major changes in 1979 and 1980 following a relatively stable period between 1973

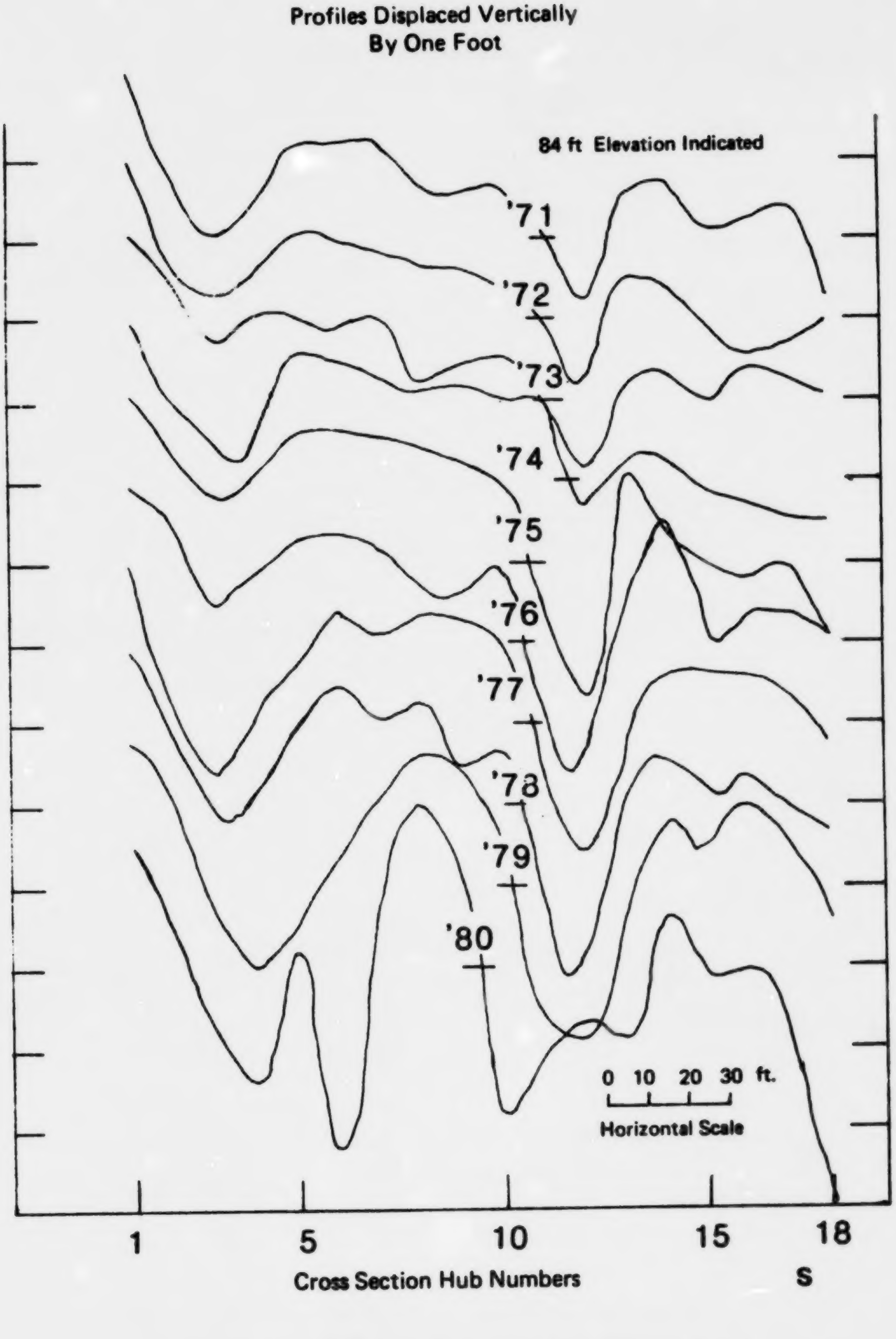

Fig. 7. Longitudinal profiles of the streambed in study reach VIII within the careful treatment (Treatment 2).

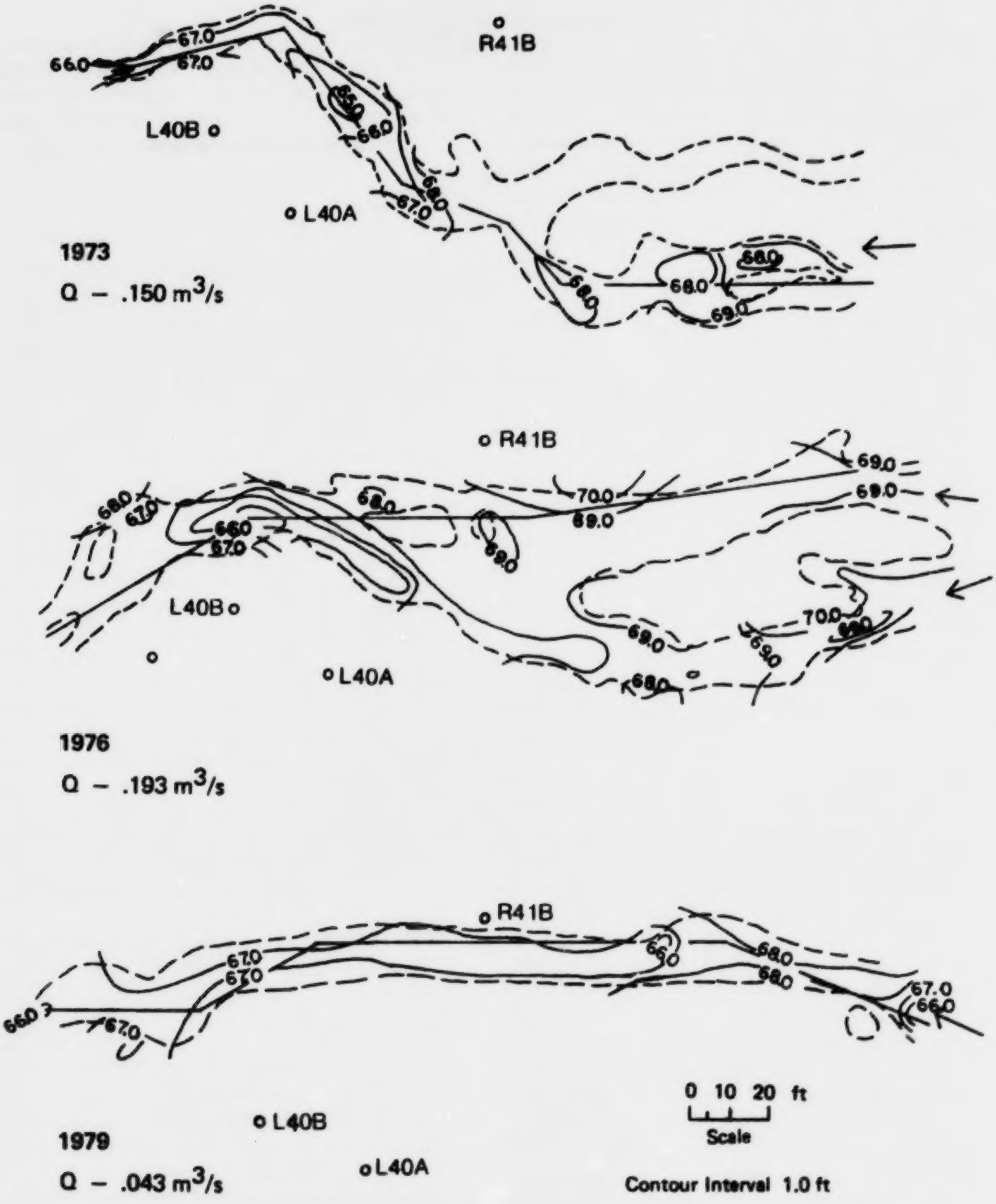
R41B
66.0
67.0
67.0
L40B
L40A
68.0
68.0
68.0
67.0
68.0
68.0
68.0
69.0
1973
Q – .150 m^3/s
R41B
69.0
69.0
70.0
69.0
68.0
68.0
67.0
66.0
67.0
69.0
L40B
L40A
70.0
69.0
69.0
69.0
68.0
1976
Q – .193 m^3/s
R41B
67.0
67.0
66.0
68.0
68.0
67.0
66.0
66.0
67.0
L40B
L40A
1979
Q – .043 m^3/s
0 10 20 ft
Scale
Contour Interval 1.0 ft

Fig. 8. Contour maps of the streambed in study reach VI within the intense treatment (Treatment 3). Note that the succession of pools that were apparent in 1973 and 1976 are no longer apparent in 1979.

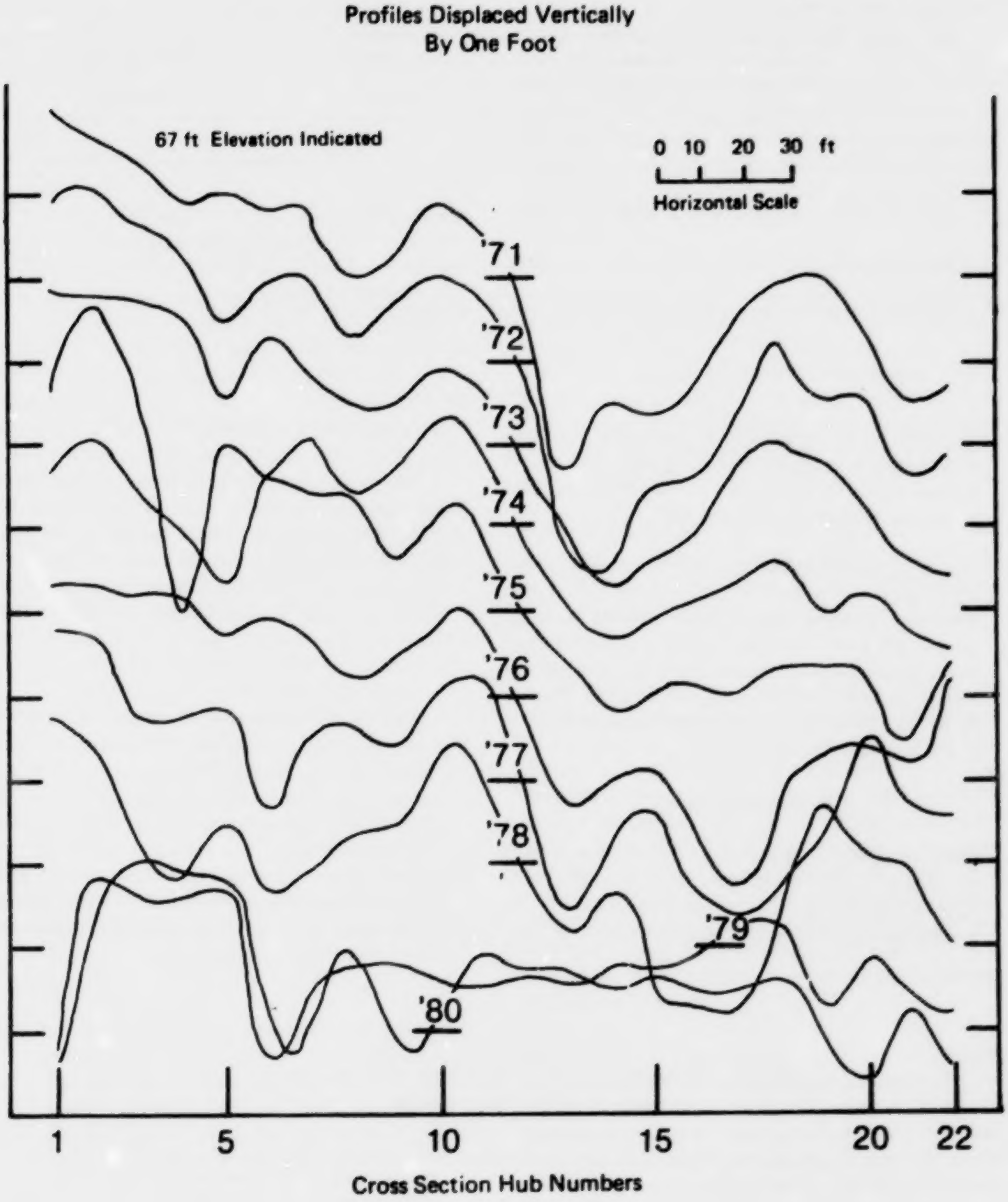

Fig. 9. Longitudinal profiles of the streambed in study reach VI within the intense treatment (Treatment 3). Note the pattern apparent between 1971 and 1978 is changed in 1979 and 1980.

Table 8. Volumes of streambank erosion within study reaches (m^3) for three streamside treatments.

	Treatment 1			Treatment 2	Treatment 3		
	Leave-Strip			Careful	Intense		
Period	II	III	IV	VIII	V	VI	VII
1973 to 1976	34.3	18.0	26.2	9.5	41.7	38.7	9.6
1976 to 1979	27.1	45.3	32.8	26.7	3.7	99.4	133.9

and 1978 in the midsection of the reach. Considerable variability is apparent in study reach VII before logging (1973 to 1978), but annual changes appear to have accelerated in 1979 and 1980.

The most obvious stream topography changes following logging are evident in reach VI of the intense treatment. Limited changes were evident in study reaches VII and VIII in the intense and careful treatments respectively. Although there was considerable annual variation, changes were not evident in reaches II, III, and IV of the leave-strip treatment or reach V of the intense treatment.

Streambank Erosion

Streambank erosion is compared for the periods 1973 to 1976 and 1976 to 1979 in Table 8. In the study reaches bounded by leave strips (Treatment 1), the erosion volumes are greater in study reaches III and IV in the 1976 to 1979 than in the 1973 to 1976 period, but the opposite occurred in reach II. In the careful treatment (Treatment 2), the erosion volume was about three times as high in the 1976 to 1979 period as in the 1973 to 1976 period. In the intense treatment, the erosion volume increased considerably in reaches VI and VII following logging (1976 to 1979) compared to prior to logging (1973 to 1976). However, the opposite trend is evident in study reach V.

Summarizing the erosion volumes by treatment (Table 9), it can be seen that the postlogging erosion volumes are more than 250% higher in the careful and intense treatments following logging, but are 32% higher in the leave-strip treatment. It should be emphasized that these are estimates based on cross-sectional profile diagrams and that analysis of the careful treatment is made difficult by the fact that logging took place in 1978. However, the trend of

Table 9. Streambank erosion volumes for three streamside treatments expressed as m^3/m of stream reach.

	Treatment 1	Treatment 2	Treatment 3
Period	Leave-Strip	Careful	Intense
1973 to 1976	0.37	0.18	0.47
1976 to 1979	0.49	0.50	1.25

increased erosion rates in the intense and careful streamside logging treatments is evident and is confirmed by field observations.

DISCUSSION

In this paper, changes in the morphology of the stream channel are related to changes in the stability and volume of large and small organic debris that took place following logging. The results indicate that the careful logging treatment and the intense logging treatment had similar results. Both resulted in reduced stability of large organic debris and introduction of small organic debris, and these contributed to some changes in the stream channel and increased streambank erosion. As pointed out earlier, the stream-channel changes may take several years to manifest themselves because they are related to storm events and other factors in addition to organic debris. The following five-step process, which describes the sequence of events following the intense and careful treatments, was proposed.

1. The size and stability of organic debris in the stream channels change following logging. The debris is less stable, pieces are smaller, and volumes are reduced.

2. Coho fry populations increase in the summer with the added fine debris.

3. Winter streamflows alter the channel as a result of the removal of stable debris and the addition of unstable debris. Movement of debris results in changes in the stream channel and increased streambank erosion.

4. Coho fry populations decrease with the redistribution of debris, which alters the stream channel and reduces rearing habitat. Downstream chum populations may be adversely affected by changes in the quality of spawning habitat.

5. Salmonid populations from the watershed are affected by the changes in spawning and rearing habitat.

The previous study (Toews and Moore 1982) provided data that supported the first step in the five-step sequence for the intense treatment, as well as presenting preliminary data and observations on steps 2, 3, and 4. In the study reported here, two additional logging treatments, as well as changes in channel morphology, are analyzed. The changes suggested in step 3 are clearly evident in one of the three intensively treated reaches, but are less apparent in the other two. There is limited evidence of channel morphology change in the carefully logged reach. However, the data in this report only extend one winter after the logging treatment.

Evidence for changes in coho fry populations within treatment areas (step 4 in the sequence) is presented in the paper by Scrivener and Anderson in these proceedings. Scrivener and Anderson report an initial population increase immediately after logging, but a population decrease several years following logging. The population decrease seen in the intense treatment was not noted in the careful treatment, although again the time period following is limited.

Evidence of changes in gravel quality is presented by Scrivener and Brownlee (these proceedings). In part, these changes are attributed to the channel changes and streambank erosion presented earlier in this paper.

A more complete description of the sequence of events is provided in the matrix diagram presented in Table 10. This diagram presents the interrelated changes in channel debris, channel morphology, and fish habitat that either occur or may occur following logging, particularly in the intense logging treatment. The data in this report only addresses short-term changes following logging, although in Table 10 a section on potential long-term changes has been added. The obvious question is whether the changes that are observed demonstrate the extent of the changes or if the system is simply at the beginning of a series of changes.

Several years of continued observation of the channel indicate that the channel is changing considerably on an annual basis. A new high water channel, formed in the intense treatment area as the result of a diversion by a pile of small organic debris, is gradually being enlarged during successive storms. Because this diversion is greater than 100 m in length, it likely will result in the most significant channel change in Carnation Creek since the study began. It was not possible from the data to determine if channel morphology changes are increasing or decreasing in the short term. However, in at least the intense treatment, considerable changes appear evident during successive high streamflows.

Table 10. A matrix of actual and potential channel debris, channel morphology, and fish habitat alterations versus time and activity phase. The changes in each of the three treatments are indicated by the numbers in brackets (1, leave-strip treatment; 2, careful treatment; and 3, intense treatment).

Activity Phase	Channel Debris	Channel Morphology	Fish Habitat
Undisturbed (4 to 6 years)	(1, 2, 3) Stable but dynamic.	(1, 2, 3) Stable but dynamic.	(1, 2, 3) Stable but dynamic.
Falling	(1) No debris added or removed. (2) Small organic debris added, some large debris added. (3) Small organic debris added. Large organic debris broken up.	(1) Streambanks and bed were undisturbed. (2) Streambanks slightly disturbed. (3) Streambanks disturbed by the felling of large timber.	(1, 2) Unchanged. (3) Habitat diversity increased by addition of small debris.
Yarding	(1) Unchanged. (2) No disturbance of debris. (3) Merchantable in-stream debris and material added during falling were removed. Debris deposited during falling is broken up into tops, chunks, and limbs and remain in the channel. Debris is well distributed throughout the streambed.	(1) Unchanged. (2) Streambanks slightly disturbed. (3) Numerous instances of streambank disturbance were noted during yarding of large material.	(1) Unchanged. (2) Mostly unchanged. (3) Habitat diversity further increased by the distribution of small debris.
First year after logging	(1) Blowdown of timber accelerated. (2) Small debris moved from the stream margins to form accumulations in the channel. (3) Small debris formed numerous accumulations at bends in channel and at downstream end of intense treatment.	(1) Unchanged. (2) Mainly unchanged. (3) Minor changes were noted. Some streambank erosion and channel bed changes noted.	(1) Unchanged. (2) Unchanged. (3) Habitat diversity is decreased by removal of scattered small debris by streamflow.
Second and subsequent years following logging	(1) Blowdown of timber accelerated. (2) Jams of small debris are beginning to erode. (3) Debris jams formed in the first year after logging gradually erode during successive storms.	(1) Unchanged. (2) Some streambed profile changes. (3) Streambank erosion is increased and streambed is changed in some of the study reaches. A new channel is forming during successive storms as a result of diversion by debris.	(1) Unchanged. (2) Changes not evident. (3) Salmonid populations are decreased as a result of streambed changes.
Potential long-term changes	(1) Old-growth timber will continue to be added until all the trees have blown down. (2, 3) Fine debris from logging will gradually be removed by high flows. Existing in-channel debris will gradually decay. New material may be added towards the end of successive rotations. Material added will be smaller than existing debris.	(1) Channels may be altered as a result of accelerated blowdown. (2, 3) Channel diversity may gradually decrease as a result of the lack of large debris.	(1) Pools may be gradually altered by addition of blowdown timber. (2, 3) Habitat diversity may gradually decrease as a result of the lack of addition of large old-growth material.

The nature of the interaction between the channel and the adjacent stand of timber has probably been permanently altered in the intense and careful treatments. The particular form of the channel in its natural condition was caused by the gradual addition of root wads and large debris from windfalls from the adjacent stand of timber containing many trees several hundred years old. Rotation age of the new stand will likely be about 75 years and, hence, material of the size that is presently in the channel will never again enter the channel. Material which is added will be smaller and will likely only be added towards the end of successive rotations. Second-growth stands will likely be much more windfirm than the existing old-growth stands, causing less input.

Added fine debris in streams may result in channel scour events, as described by Swanson and Lienkaemper (1978). In Carnation Creek, there was concern that the large amounts of fine debris added by logging would cause such an occurrence. However, it appeared that the accumulations of small debris added in the intense treatment immediately after logging were being eroded gradually and the chances of scour events are therefore diminished.

Another obvious question might be whether the channel changes are due to higher peakflows or increased stormflow volumes. Elsewhere in these proceedings, Hetherington presents evidence that neither peaks nor volumes have been altered significantly following logging. Both the data presented herein and ongoing observations indicate that on-site circumstances, rather than altered flows, have led to individual alterations in channel morphology.

The management implications of this work arise from the findings that the intense and careful logging treatments both resulted in similar changes in organic debris and stream channel morphology, while the leave-strip treatment did not cause any similar changes. The obvious implication that leave strips are therefore effective in protecting stream channel integrity and fish habitat requires clarification.

In the intense logging treatment, a number of trees of large size were felled into the stream channel and yarded out. Alder trees along the stream edge were also felled to facilitate streamside yarding and many of these fell into the stream channel. Additionally, a number of pieces of old stable debris were yarded out and broken pieces of tree trunks, limbs, and branches were left in the stream channel. The results which showed changes in organic debris were predictable and not unexpected.

The careful treatment was designed to avoid these types of obviously harmful activities, and the results which show that it had similar impacts as the intense treatment are unexpected. The streamside logging was carefully done. The trees which were felled across the stream after an on-site inspection were carefully removed from the channel. Alder was not felled into the stream and stable debris was not removed. Some trees that were in a canyon proved difficult to log. They were left and blew down subsequent to logging. These trees may be a source of some of the debris appearing in study reach VIII. However, one of the main reasons for the changes that are reported in the results was the introduction of small organic debris and of small pieces of large organic debris subsequent to logging. This debris was not deposited in the stream channel directly but was left along the stream margin and apparently floated into the stream channel during high stormflows. The careful stream treatment did not prevent debris entering the stream following logging. If this type of treatment is to be effective, additional precautions will have to be taken to prevent debris accumulations on the stream margins or in areas which are inundated during high flows.

The leave strips in study reaches II, III, and IV did prevent the changes in large organic debris and channel morphology that were observed in the reaches subject to the intense and careful treatments. However, these leave strips have been at a cost of timber values foregone. In two of the three study reaches and in both the narrow and wider leave strips, there has been considerable blowdown. In the vicinity of reach II, six trees comprising about 40% of the original standing volume were blown down. In the vicinity of reach III, five trees comprising about 20% of the original volume were blown down (Schultz International Ltd. 1981). The standing timber adjacent to study reach IV suffered heavy blowdown and has now been logged.

The type of large debris introduced to a stream by blowdown is completely different than that introduced by logging activities and probably has different impacts. Indeed, one of the most compelling reasons for retaining leave strips is the expectation that, over time, trees will blow down and become large organic debris in the stream channel. It is not the intent of this paper to evaluate the impacts of the blowdown in the Carnation Creek leave strips but it must be noted that blowdown has occurred and may lead to changes in the channel. In future, modification of the type of leave strip or use of different logging techniques or layout of clearcuts may be more successful in meeting the objectives of maintaining the stability of large organic debris and of the stream channel while harvesting valuable timber.

SUMMARY
AND
MANAGEMENT RECOMMENDATIONS

Carnation Creek is typical of the many second- and third-order coastal streams that normally contain large quantities of organic debris and that have sufficient discharge and velocity to move this debris. This study has reported the effects of streamside logging on the stability, quantity, and distribution of in-stream debris in logged reaches of Carnation Creek and has reported initial changes in stream morphology that appear to be the result of the changes in debris. The following recommendations are directed at avoiding the type of changes that are reported for the intense and careful treatments. The recommendations stress the importance of maintaining the stability and distribution of large debris that exists in the prelogging condition.

1. Trees should not be felled into or yarded across the stream channel. Falling and yarding trees into Carnation Creek introduced a considerable quantity of large and small debris which subsequently moved and caused debris jams in the four years following logging. Falling and yarding into the stream channel also broke up several pieces of large stable debris, causing them to become less stable.

2. Large stable pieces of debris should not be disturbed or removed during yarding. The removal of large debris caused a substantial reduction in the volume of large debris in some of the logged reaches of Carnation Creek and resulted in channel configurations less desirable for salmonid production.

3. Alder should not be felled into the stream. In the intense treatment, alder was killed by "hack and squirt" and then felled. Many of these alder trees entered the stream channel and, because they were generally small and light, now form a substantial part of the debris jams that have formed below and within the logged reaches.

4. Careful streamside logging should include removal of small pieces of debris such as limbs, branches, and small broken chunks from the stream margins and streamside areas subject to flooding. Follow-up work after logging should be conducted to remove small debris that has entered the stream and accumulated in jams. This careful handling of small debris will be important in avoiding the changes we have reported in reach VIII.

5. Leave strips can be an effective method of maintaining the prelogging conditions in the stream and do provide a source of large organic debris for the stream in the future. In Carnation Creek, however, the effectiveness of the leave strips has been reduced by blowdown. Leave strips should, therefore, only be left after careful site-specific consideration of the risk of excessive blowdown. Maximum effort should be directed to planning windfirm leave strips.

6. Movement of debris introduced by logging continues for at least four years after logging. Stream-rehabilitation or debris-removal programs should be designed in recognition of this continuing movement of debris and repeat programs may be necessary. Only potentially unstable debris should be removed during any debris removal programs.

7. Bridges and culverts should be designed to allow the passage of large organic debris. This study indicates that large debris forms a part of the total load transported by streams under natural conditions.

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QUESTIONS
TO D.A.A. TOEWS AND M.K. MOORE

Question *(Unidentified)*: This question is for Peter Tschaplinski or for Dave Toews. With the reduction in stability of debris following logging, I assume at least part of this material is making its way out of Carnation Creek. My question is, Is this stuff depositing in the estuary where it might be doing good for the fish? or Is it simply being shoved back up into the high water line where it isn't doing much good?

Answer *(P. Tschaplinski)*: The estuary changes really dramatically between the summer and the winter. During the winter months, so much movement of gravel and rocks occurs that you can hardly recognize where the pools and riffles have been at low tide the previous summer. From winter to summer again, you have a huge change in the actual physical appearance of the estuary. The actual sequence of riffles and pools often changes twice during this period, from one summer to the next spring. A lot of debris does accumulate during parts of the winter, but in the spring, let's say May and June, it's gone.

Comment *(G.F. Hartman)*: I think that Bruce Andersen might be a good person to comment on that because he's been responsible for the fences and has some feeling for how much debris has gone over the top of the fence. Bruce, do you have an observation on whether or not that's changed through the logging period?

Answer *(B. Andersen)*: I get the impression that there is probably some increase, but I think most of it's still hanging up upstream on the logjams and has not moved over the fence yet.

AN ANALYSIS
OF THE CARNATION CREEK GRAVEL-QUALITY DATA
1973 TO 1981

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ABSTRACT

A project to study the effects of logging on a small salmonid nursery stream commenced in 1970 at Carnation Creek on the west coast of Vancouver Island, British Columbia. The project is designed for five years of prelogging calibration (1970 to 1975), six years of logging (1975 to 1981), and five years of postlogging assessment (1981 to 1986). A component study of this multidisciplinary project is the assessment of spawning gravel quality. More than 1200 gravel cores, intergravel-dissolved oxygen, and intergravel permeabilities have been obtained since 1973 to assess changes in the quality of the gravel and the corresponding changes to survival and condition of salmon embryos. Cores were split and analyzed as three layers. Fines less than 9.55 mm were found to increase with depth. A seasonal trend was exhibited in the top and middle layers, as particles less than 0.297 mm decrease between early autumn and the following spring. After logging commenced, fines less than 9.55 mm increased in the top layer over prelogging levels. Major accumulations of particles between 9.55 mm and 0.297 mm occurred in the top layer of the lower 2 km of stream after the first major postlogging freshet. Concurrently, fines decreased in the bottom layer and intergravel permeability and dissolved oxygen declined. The addition of data from August 1980 to September 1981 indicated that all classes of fines were still accumulating in the streambed. Marked reductions in chum and coho salmon egg-to-fry survival were noted. All studies are continuing until project completion.

INTRODUCTION

Much has been written about changes in fluvial processes and sedimentation being influenced by land-use practices, including timber harvesting (1, 2, 3, 4, 5). It is generally accepted that high levels of sedimentation result in lowered salmon production (4, 6), but the material is usually not traced to its source. By understanding how the processes function and how they influence stream biota, the results should be more easily extrapolated to other watershed ecosystems. This is a preliminary report on the quality of the streambed environment at Carnation Creek. Integration of these results with other fluvial processes is anticipated on study completion in 1986.

Considerable research has been reported on the accumulation of fines in the bed and its impacts on the survival and fitness of salmonid embryos and fry (7, 8, 9, 10). Mortality in the streambed is caused mainly by two processes (11): (i) reduced oxygen because of low concentration (10, 12) and reduced delivery rate (13); and (ii) the physical barrier to fry emergence of fines in the gravel interstices (7, 9, 11).

The immediate objectives of the gravel-quality programs are to assess the effect of current forest-harvesting practices on spawning gravel composition, intergravel dissolved oxygen, and intergravel permeability; and to establish any relationships existing between spawning gravel composition oxygen and permeability and to determine their influence on the survival or condition of emerging fry.

Two concurrent gravel-sampling programs were begun at Carnation Creek in 1973. For one program, spawning gravel has been sampled below (area 1), within (area 2), and above (areas 3 and 4) a segment of intense streamside logging. The second, more intensive investigation has been undertaken in an area near the estuary used by chum salmon. This report presents analyses on data collected on gravel composition, subgravel oxygen, and subgravel permeability between January 1973 and September 1981. Chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) incubation survival is also reported for 1971-1972 through 1981-1982. Data on chum fry condition from the intensive program are not reported here. A final report on the full program is anticipated on study completion in 1986.

WATERSHED DESCRIPTION

Carnation Creek is a small stream which enters Barkley Sound on the west side of Vancouver Island (Fig. 1). It contains coho (*O. kisutch*) and chum (*O. keta*) salmon, steelhead (*Salmo gairdneri*) and cutthroat trout (*S. clarki clarki*), and approximately 10 km^2 of overmature western hemlock-amabilis fir-western red cedar forest which until 1975 was entirely unlogged (14). The high annual rainfall (260 to 350 cm), runoff patterns, and forest associations are fairly typical for western Vancouver Island and the coast mainland of British Columbia (1, 14).

Flows recorded at the main hydrological weir (Fig. 1), about 400 m above tidal influence, ranged from 0.017 m^3/sec (0.6 cfs) in late summer to peaks of 45 m^3/sec (1600 cfs) in January 1982. Freshets of 37 m^3/sec (1300 cfs), 34 m^3/sec (1200 cfs), and 38 m^3/sec (1350 cfs) occurred in March 1972, February 1977, and November 1978, respectively.

The topography of the basin features rugged terrain of steep slopes to 700 m elevation and a narrow valley bottom through which the stream meanders. The area was heavily glaciated during the Pleistocene period. Slope soils are shallow, underlain with bedrock mainly of volcanic origin. Soils in the valley bottom are derived from recent alluvium which are underlain by gravel deposits (as deep as 4 m) and bedrock (14, 15, 16).

Carnation Creek drops approximately 62 m in the lowest 3.2 km (average slope 1.9%). In this segment of stream, the substrate is characterized by gravel and a few cobbles greater than 15 cm in diameter. The channel contains numerous accumulations of organic debris associated with fallen trees. Extensive gravel bars indicate considerable gravel movement. The next 0.9 km of stream, 3.2 to 4.1 km above tidal influence, is confined to a narrow bedrock canyon with an average gradient of 8.4%. The channel contains numerous logjams with gravel accumulations behind them. The next 1.1 km of stream, 4.1 km to E weir (Fig. 1), flows over a gravel and cobble substrate with some small boulders and outcrops of bedrock (16).

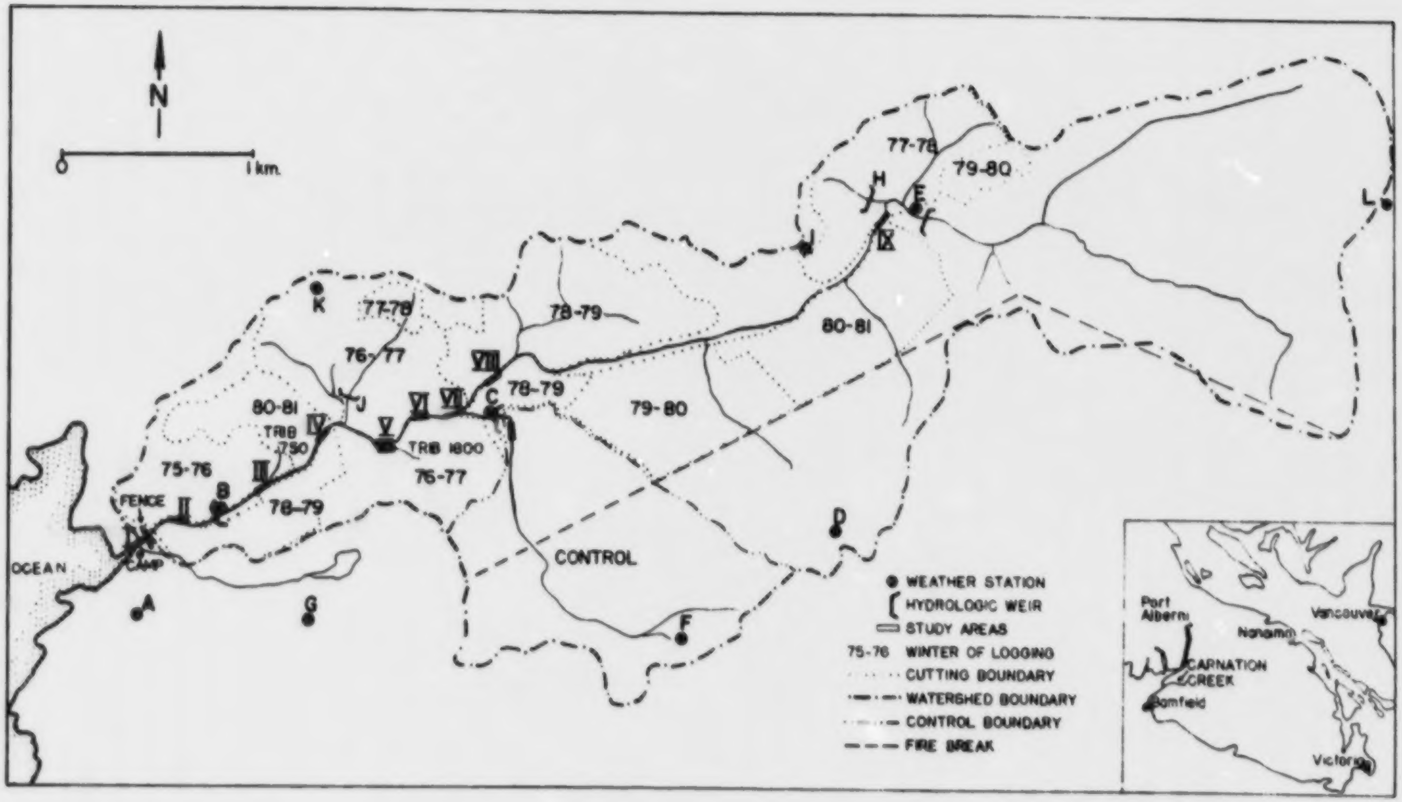
STUDY SECTIONS

Section I

This study section is approximately 10 m in width and 100 m in length. There are 45 fixed stations located on eight transects over approximately 40 m of stream (Fig. 2). The two transect groups are located on riffles that are separated by a pool. This section is intertidal and downstream of the fish-counting fence (Fig. 1). Approximately 2000 chum salmon spawn in this area annually.

Sections II to IX

These study sections are located within the various logged openings which received four different experimental streamside treatments. Stream Sections II, III, and IV formed Area 1; they were downstream of the intensive streamside treatment and were logged between 1976 and 1980 (Fig. 1). All deciduous and minor vegetation along the streambank was undisturbed by logging, and any merchantable timber which could not be felled away from the stream was left standing. Sections V and VI (Area 2) were logged during the winter of 1976-1977; these were the "intensively treated" sections. The streamside treatment consisted of hand-applied herbicide (hack and squirt) to seed alder in 1975, falling all merchantable trees and high lead yarding those trees that fell across the stream (Fig. 1). Area 3 included Sections VII and VIII. Section VIII was logged in 1978-1979, but only a few selected trees, upstream of the section, were felled across and lifted out of the stream. Minor streambank vegetation was undisturbed, but remaining seed alders were felled away from the stream. Section VII was logged in 1977, but grouped with Section VIII in Area 3, as it was on the upper-cutting boundary of the intense treatment because few trees were felled across it and because minor vegetation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WATERSHED BOUNDARY
CONTROL BOUNDARY
FIRE BREAK
Port Alberni
Nanaimo
Vancouver
CARNATION CREEK
Bamfield
Victoria

Fig. 1. Carnation Creek Watershed showing the main channel and tributaries; location of hydrometeorological stations, fish-counting fence, stream study sections, and clearcuts. Inset shows the location of Carnation Creek on Vancouver Island.

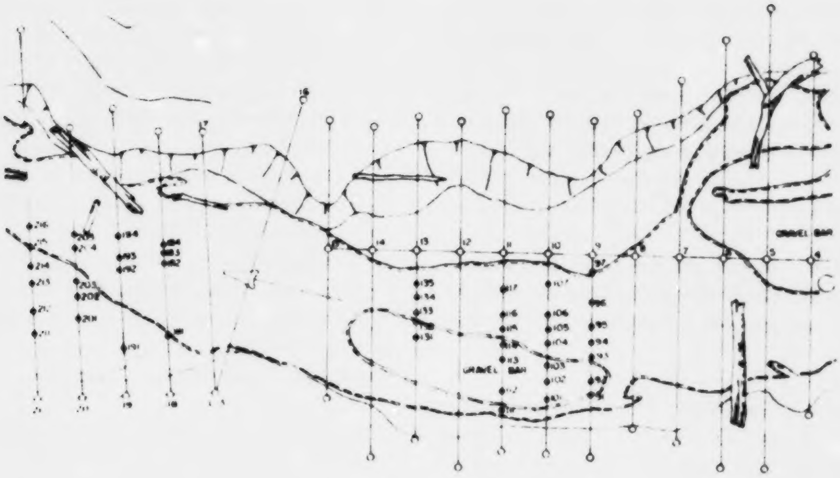

Fig. 2. Stream Study Section I at Carnation Creek depicting 45 sampling sites, survey hubs, and streamflow direction.

was not disturbed. Area 4 consisted of Section IX. It served as an unlogged control until September 1980. There are 4 to 10 fixed stations for gravel sampling located in each of these sections.

METHODS AND PROCEDURES

A. Sample Collection

In Study Sections II to IX, 60 gravel samples were collected from the same sites once per year during the summer months. Figure 2 identifies the 45 fixed stations where gravel and oxygen samples and permeabilities were collected in Section I. In this section, the order of sampling entailed the collection of subgravel water for dissolved oxygen determination, measurement of subgravel permeability, and collection of a gravel core at each site on three occasions each year. The program was undertaken during September, December, and March to reflect those chum salmon life-history phases of pre- and postspawning and prefry emergence. On completion of the March series, 25 emergence traps were placed over those sites within the "low-flow" wetted perimeter to collect emerging fry for condition analysis. Details of each sampling component include:

1. Subgravel-dissolved oxygen samples were collected using a stainless steel syringe designed by Peter Ryan (197). A 500 mL sample of water was extracted from approximately 20 cm below the gravel surface and "fixed" in a standard B.O.D. bottle. Surface-water samples were also collected from two sites within Section I. Samples were not obtained for the postspawning period in January 1978.

2. Subgravel permeability measurements were taken with a plastic cylinder, hand-vacuum pump, and Mark VI standpipe (18 and 19). Water was pumped from the standpipe, held under a one-inch head, and measured in millilitres per second pumped. Measurements were repeated until consistent volumes were obtained.

3. Gravel samples were taken using the acetone-dry ice frozen core technique (20). Briefly, the procedure was as follows: a steel probe attached to the sampling "pot" is driven approximately 30 cm into the gravel, acetone and dry ice are added to the "pot" and allowed to cool for approximately 20 minutes, and then the probe (with a 20 cm diameter frozen core) is extracted. The gravel core was

split horizontally into three subsamples—top (12 cm), middle (12 to 24 cm), and bottom (24 to 35 cm)—bagged independently and transported to the laboratory facilities in Vancouver for analysis. The annual gravel cores from Sections II to IX were split in two (top/bottom) and also analyzed in Vancouver.

B. Sample Analysis

1. Dissolved oxygen was determined by the Hach-modified-Winkler technique, titrating 200 mL with an accuracy of 0.1 mg/L (Hach Chemical manual).

2. Subgravel permeabilities in millilitres per second were converted to subsurface flows in centimetres per hour following the methods of Terhune (18).

3. Gravel composition analysis was undertaken using modified techniques outlined by T.W. Lambe (21). In the interest of efficiency, only five sieves (U.S. Bureau of Standards) were used (9.55, 2.38, 1.19, 0.297, and 0.074 mm), reflecting a biological emphasis on the "finer" fraction of those gravels studied. Sample analysis was by dry sieving. Particles less than 0.074 mm were retained for ashing in order to determine the organic (carbon) fraction. Since August 1978, the weight of material which was too large to pass through the sample splitter (22.2 mm) has also been recorded. More recently, the average dimension of the largest particle in each sample was recorded (length plus width divided by 2). This analysis separated the sample into six components which are similar to the U.S. Department of Agriculture Classification of gravels, pea gravels, coarse sands, medium sands, fine sands, and silts-clays (Fig. 3).

C. Data Analysis

The gravel composition, oxygen, and permeability data were stored on IBM tape. During analysis, gravel composition weights were converted to percent of total sample weight which passed through each sieve (9.55, 2.38, 1.19, 0.297, and 0.074 mm) and stored in disc files. Oxygen concentrations were stored as percent of surface water concentration. The MIDAS system (Michigan interactive data analysis system, 22) with its statistical packages was run on the University of British Columbia computer. This well-documented system handled the data files and could perform most common statistical tests. Since the sampling programs were designed to compare three gravel depths (top,

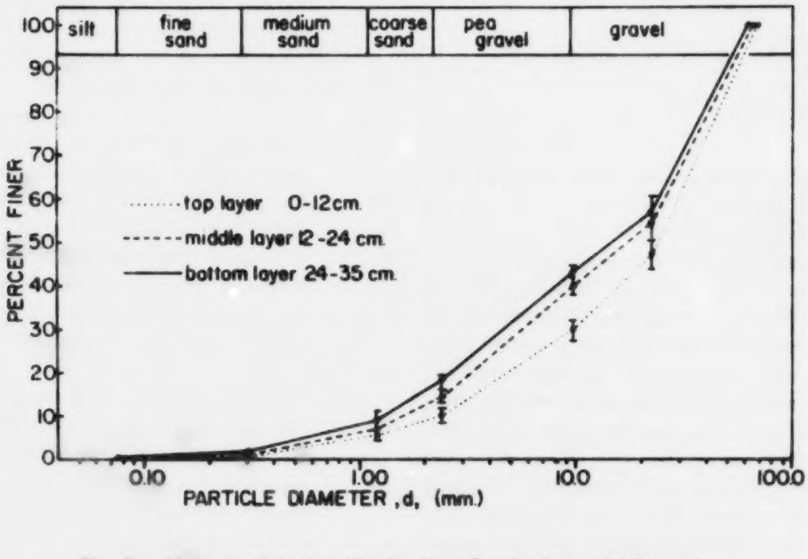

Fig. 3. Mean particle-size distributions for the top, middle, and bottom layers of spawning gravels in Section I of Carnation Creek.

middle, and bottom layers), three time periods (pre-, during, and postlogging), three annual seasons (prespawning, postspawning, and prefry emergence), and four streamside treatments (Areas 1 to 4), initial analysis was suited to two- or one-way analysis of variance tests. When these tests were statistically significant, the differences were explored further by either pairwise or Student-Newman-Keul range tests.

The time periods used were: (1) January 1973 to August 1976, prelogging; (2) September 1976 to October 1978, logging; and (3) November 1978 to August 1980, post-November 1978 freshet. A second, more recent analysis included data from August 1980 to September 1981. These data were included in the post-November 1978 freshet period and the means are expressed on the figures as dotted lines. The November 1978 freshet was used to separate periods two and three, because it was the only major freshet to occur since the intense logging treatment in 1976-1977. Many changes in channel morphology and debris, which occurred during this flood, were not observed during similar or larger freshets in March 1972, November 1975, and February 1977. The February 1977 freshet occurred before any timber was yarded from the stream.

Examination of statistical relationships between fines in the bed, dissolved oxygen, and permeability proved more complex than initially anticipated. This will be reported later when more data are available.

RESULTS AND DISCUSSION

Gravel Composition in Study Section I

Since January 1973, more than 1200 gravel cores have been obtained from the chum spawning area in Carnation Creek. As the finer fraction of 20 gravel cores taken in 1971 was found to be quite low (less than 35%), samples since January 1973 were split into three layers and analyzed separately in order to increase the possibility of detecting changes.

The quantity of material less than 9.55 mm, expressed as a percentage of total weight, varied between 5% found in a top-layer sample and 78% found in a bottom-layer sample. Most samples contained 25% to 45% of these smaller particles. Confidence limits about the means were +/- 3% (Fig. 3). Fine particles, classed as sand or smaller, formed 8% to 20% of most samples. Fine sand, silt, and clay portions were usually less than 2% (Fig. 3).

Other authors recommend using the geometric mean diameter "dg" as a simple description of the bed's potential as spawning gravel (23). The "dg" is obtained from the square root of the product of the particle diameters below which 84% and 16% of the gravel is finer. This procedure is statistically sound only if the particle-size distribution is lognormal in configuration (24), which appears to be the case for Carnation Creek data (Fig. 3).

A "dg" of 11.4 mm was calculated from cores which were obtained since August 1978. These results indicated that the chum spawning area of Carnation Creek contained good-quality spawning gravel with quantities of fines similar to or lower than those obtained from other downstream reaches sampled in the Pacific Northwest (10, 19, 25, 26, 27).

Subsamples compared for the three depths (top, middle, and bottom) and the three time periods (January 1973 to August 1976, September 1976 to October 1978, and November 1978 to August 1980) for all five classes of fines (< 9.55, < 2.38, < 1.19, < 0.297, and < 0.074 mm) indicated highly significant differences between gravel layers for all particle-size classes (Table 1). Significant differences between time periods were observed for four of the five particle-size classes. There were significant interactions between these two factors (Table I). Multiple range tests on means of each layer indicated that they represented three homogeneous subsets for all particle-size classes. Significantly greater fines were observed in the bottom layer than in the middle layer and significantly greater fines were found in the middle than top layer (Figs. 4 and 5).

Lower levels of "fines" near the bed surface have been observed in other streams of the Pacific Northwest and it was thought to reflect the presence of an armor layer (an abundance of relatively large particles) at the surface of the bed (23, 24). This was evident by the greater differences in mean percentages between the top and middle layers than between the middle and bottom layers (Figs. 4 and 5). Significant differences between the middle and bottom layers reflected an increase of fines in the deeper layers, suggesting more frequent cleaning of the surface material and little sorting of the deeper layers. Owing to this distinct increase in fines with depth, statistical treatments of the data were undertaken for each depth zone.

Table 1. F statistics from analyses of variance on percent fines less than 9.55, 2.38, 1.19, 0.297, and 0.074 mm from Carnation Creek gravel cores in Section I. NS = not sign., * = sign. 0.05, ** = sign. 0.01, *** sign. 0.001. Means are shown in Figures 4 and 5.

Analysis	No. of Samples	< 9.55 mm	< 2.38 mm	< 1.19 mm	< 0.297 mm	< 0.074 mm
Two-way ANOVA:	2940					
Depth (i)		216.7^{***}	292.9^{***}	290.8^{***}	31.7^{***}	94.6^{***}
Time periods (ii)		8.6^{***}	1.2 NS	3.8^{*}	7.0^{***}	45.0^{***}
Interaction		4.8^{***}	6.7^{***}	7.9^{***}	3.5^{**}	10.7^{***}
One-way ANOVA times 1, 2, and 3:						
Top-layer time periods	980	5.3^{**}	8.4^{***}	7.2^{***}	0.4 NS	1.0 NS
Top-layer pairwise tests		$1 < (2 \approx 3)$	$(1 \approx 2) < 3$	$(1 \approx 2) < 3$		
Middle-layer time periods	980	3.6^{*}	0.9 NS	2.1 NS	2.6 NS	2.2 NS
Middle-layer pairwise tests		$1 < 2 > 3$				
Bottom-layer time periods	980	9.6^{***}	5.6^{**}	8.2^{***}	4.5^{**}	6.9^{**}
Bottom-layer pairwise tests		$(1 \approx 2) > 3$	$(1 \approx 2) > 3$	$(1 \approx 2) > 3$	$1 > 3$	$(1 \approx 2) > 3$
One-way ANOVA:						
Top-layer seasonal periods (iii)	980	1.1 NS	2.1 NS	1.8 NS	4.4^{*}	3.9^{*}
Top-layer pairwise tests					$(a \approx b) > c$	$a > c$
Middle-layer seasonal periods	980	0.6 NS	0.0 NS	0.4 NS	4.9^{**}	3.5^{*}
Middle-layer pairwise tests					$(a \approx b) > c$	$a > (b \approx c)$
Bottom-layer seasonal periods	980	5.5^{**}	2.9 NS	3.4^{*}	1.9 NS	2.7 NS
Bottom-layer pairwise tests		$a < (b \approx c)$		$a < (b \approx c)$		
One-way ANOVA time periods 1, 2, and 4:						
Top-layer time periods	1154	13.2^{***}	27.3^{***}	28.2^{***}	13.7^{***}	2.1 NS
Top-layer pairwise tests		$1 < (2 \approx 4)$	$(1 \approx 2) < 4$	$(1 \approx 2) < 4$	$(1 \approx 2) < 4$	
Middle-layer time periods	1154	4.1^{*}	9.5^{***}	8.4^{***}	3.0 NS	-------
Middle-layer pairwise tests	1154	$1 < (2 \approx 4)$	$(1 \approx 2) < 4$	$(1 \approx 2) < 4$	$1 < (2 \approx 4)$	
Bottom-layer time periods	1154	1.1 NS	0.6 NS	1.9 NS	7.7^{***}	10.0^{***}
Bottom-layer pairwise tests					$1 > 4$	$(1 \approx 2) > 4$

(i) Depth:
1. Top layer
2. Middle layer
3. Bottom layer

(ii) Time periods:
1. January 1973 to August 1976
2. September 1976 to October 1978
3. November 1978 to August 1980
4. November 1978 to September 1981

(iii) Seasonal periods:
a. Prespawning
b. Postspawning
c. Preemergence fry

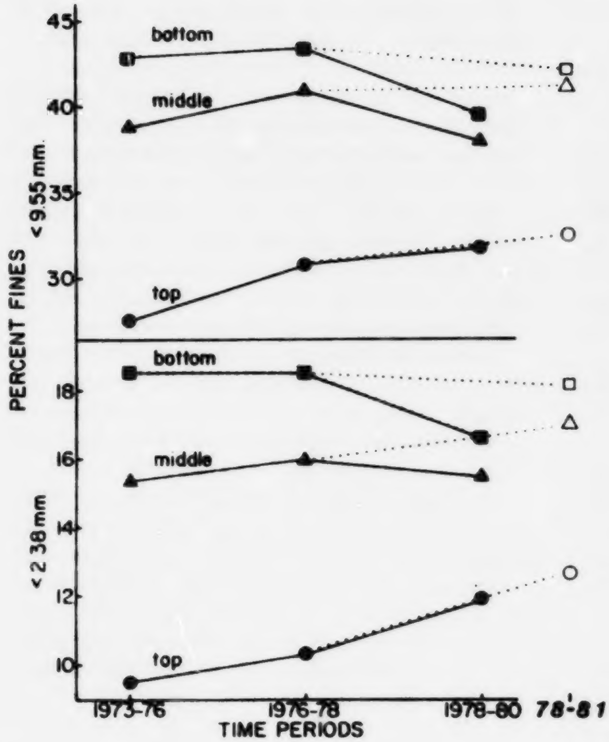

Fig. 4. Mean percent of particles less than 9.55 mm and 2.38 mm in the top, middle, and bottom layers of gravel cores from Section I of Carnation Creek. Time periods shown are January 1973 to August 1976, September 1976 to October 1978, and November 1978 to August 1980. The means from the November 1978 to September 1981 time period are connected by dotted lines.

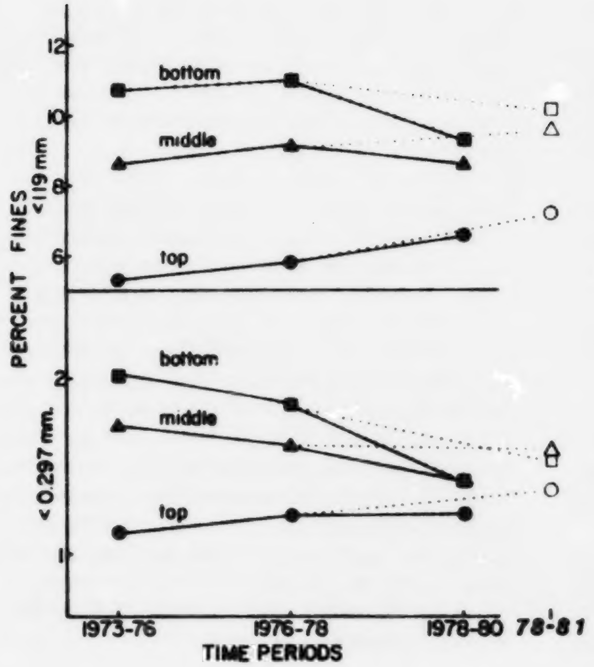

Fig. 5. Mean percent of particles less than 1.19 mm and 0.297 mm in the top, middle, and bottom layers of gravel cores from Section I of Carnation Creek. Time periods shown are January 1973 to August 1976, September 1976 to October 1978, and November 1978 to August 1980. The means from the November 1978 to September 1981 time period are connected by dotted lines.

In the first analysis, results for each level of the bed were compared for the three time periods (prelogging, postlogging, post-1978 freshet) for each particle-size class. Top-layer subsamples were significantly different among the time periods for particle-size classes less than 9.55, 2.38, and 1.19 mm, but not for those less than 0.297 mm and 0.074 mm (Table 1). These differences were the result of increased fine particles less than 9.55 mm prior to and after the 1978 freshet and of increased fine particles less than 2.38 mm and 1.19 mm after the freshet (Table 1). Since no increase in fine sand or smaller particles (< 0.297 mm) were noted during this period, the increases in particles less than 1.19, 2.38, and 9.55 mm were entirely the result of additions of medium-coarse sands and pea gravel either after logging or after the first major postlogging freshet (Figs. 4 and 5). In the top 12 cm of the bed, the composition of these three components has increased from 27% to 32% (Fig. 4). Half of this 5% increase, 2.3%, was coarse and medium sand (11.8% to 9.5% from 2.38 mm, Fig. 4).

In the middle layer, a significant difference among the three time periods was obtained only for particle sizes less than 9.55 mm (Table 1). This resulted from a slight increase in mainly pea gravels after logging and then a decrease again after the first major postlogging freshet (Fig. 4).

In the bottom layer, a significant difference among time periods was obtained for all five particle-size classes (Table 1). This resulted from a decline in fines of all size classes after the November 1978 freshet (Figs. 4 and 5). Fines less than 9.55 mm had declined from 44.6% to 39.4% in this layer of the bed (Fig. 4).

For the postfreshet period, the mean percent fines in each gravel layer were greater when an additional 180 samples (August 1980 to September 1981) were included in a second analysis. In the top layer, the mean of particles less than 9.55, 2.38, 1.19, and 0.297 mm increased another 0.97, 0.74, 0.46, and 0.13%, respectively (Figs. 4 and 5). Fine-sand particles (< 0.297 mm) had now increased significantly (F = 13.7***, Table 1) since November 1978, but silts and clays (< 0.74 mm) had not increased. In the middle layer, fines less than 9.55, 2.38, and 1.19 mm now showed significant increases (Table 1). In the bottom layer, the significant decline observed earlier for particles less than 9.55, 2.38, and 1.19 mm was no longer apparent (Table 1). Fines were continuing to accumulate in the streambed of Section I and gravel quality was still declining between August 1980 and September 1981.

Results for the three seasonal collection periods (prespawning, postspawning, prefry emergence) were also compared for each particle-size class in each layer. Among top and middle layers, significant differences between collection periods were obtained for particle sizes less than 0.297 mm and 0.074 mm, but they were not significant for the larger particle sizes (Table 1). The fine sands and silt-clays were either lower in the March preemergence period or higher in September to October before spawning. Significant differences between seasonal collection periods were observed for particle sizes less than 9.55 mm and 1.19 mm from the bottom layer (Table 1). Statistics of 0.066 probability were obtained for the 2.38 mm and 0.074 mm size classes. The difference was due to the greater fines of these classes in the prespawning period. Even though the values were not always significant, a trend towards an annual cycle was apparent. Fines were highest during September to October after some months of low flows; they were lowest in February to March after scouring by winter freshets.

Several other authors have noted this seasonal reduction of fines in Oregon and Alaskan streams (24, 28, 29). McNeil and Ahnell found that abundant spawners "cleaned" the fine particles from an intertidal area similar to Section I in Carnation Creek. They also noted that the spawning population was not of sufficient density to distribute many adults upstream. As a result, the upstream spawning beds were not cleaned (30). Shapley and Bishop noted that high streamflows can determine the size composition of streambed material (28).

This seasonal cycle of accumulating fines during low-flow periods and removal by the actions of spawning fish or freshets were not always apparent at Carnation Creek. Probable reasons were the erratic flows observed in the creek and the introduction of fines during winter logging activities. Freshets of 7.8 m^3/sec (276 cfs) just prior to gravel sampling in September 1978 and of 11.4 m^3/sec (404 cfs) in August 1978 were likely causes of the lower fines in prespawning than postspawning gravel cores during these years. The very slight increase in fines between postspawning 1976 and prefry emergence 1977 occurred during the most intense streamside logging treatment during the program. A close examination of suspended sediment data collected during these freshets is planned.

Overshadowing this seasonal cycle were the very significant changes to the bed that occurred after the first major postlogging freshet. The slight increase in fines after logging commenced upstream in September 1976 was apparently only in the top layer. The major freshet of November 7, 1978 produced deep-scouring and cleaned fines of all classes to a depth of at least 35 cm. Removal of large debris which appeared to armor the streambanks resulted in extensive bank erosion and changes to the morphology of the stream, thus introducing fines to the stream (31). Eroded fine sands, silts, and clays appeared to be transported as suspended sediment out of the watershed during this storm or by other freshets which occurred during this period because they were not noted during the December 1978 sampling. Mean suspended sediment concentration at B weir on November 7 was 99 mg/L, while normal background levels were 1 to 5 mg/L (32). Pea gravels and coarse and medium sands were transported downstream as bedload and accumulated in the top layer since that date.

During flume experiments, Beschta and Jackson determined that sand particles introduced to the bed became trapped in voids within the upper 10 cm and did not penetrate deeper unless the flume bed was disturbed. When flows were increased, sand was removed from only the top centimetre. Deeper cleaning occurred only after the gravel was destabilized by still higher flows (33).

It is apparent that frequent freshets at Carnation Creek prevent introduced fines smaller than 0.074 mm from accumulating in the bed for more than a year. Accumulations of sand could also be removed every few years by major freshets. These results indicated that spawning gravels in streams similar to Carnation Creek can be cleaned of accumulated fines within a few years, if the erosion from new sediment sources is arrested.

Subgravel Oxygen in Study Section I

Between January 1973 and April 1980, over 980 intergravel oxygen concentrations have been obtained from Section I. Values ranged from 0.5 to 11.4 mg/L, while concentrations between 6.6 and 12.6 mg/L were obtained from surface waters. A similar wide range of dissolved oxygen concentrations were obtained from logged streams during the Alsea Watershed Study (9, 19, 34).

Earlier in the study, all pre-1978 intergravel oxygen data expressed as percent of saturation (where 12.6 mg/L = 100%) were compared for the three seasonal sampling periods (prespawning, postspawning, and prefry emergence). Percent of saturation was significantly different among seasonal periods (F = 8.3***). Pairwise tests indicated that the mean prespawning percent (43.1%) was less than the postspawning percent (49.7%) and that postspawning was less than preemergence (52.7%). This seasonal difference probably reflected the lower surface concentrations prior to spawning and the higher ones later in the year. This phenomenon was also observed during the Alsea Study (9).

To reduce the influence of any annual cycle of surface concentrations, intergravel oxygens were expressed as a percent of mean surface concentration, which was obtained from two surface samples (Fig. 6). These percentages were compared for the three time periods (January 1973 to August 1976, September 1976 to October 1978, November 1978 to August 1980) for each seasonal period. All three seasons showed significant differences among time periods (F > 8.0***). Mean percentages were significantly less after the first major postlogging freshet during all three seasonal periods (1978 to 1980, Fig. 6). During the 1977 and 1978 prefry emergence periods, oxygen levels were also significantly lower than during prelogging (Fig. 6).

The results from the second analysis, which included data from August 1980 to September 1981, indicated the following: prespawning and preemergence levels have increased again and postspawning levels are unchanged after August 1980 (Fig. 6). These oxygen levels, however, are still significantly lower than prelogging or prefreshet values for all three seasonal periods (F = 21.2***; F = 21.4***; F = 147.3***).

Other studies have recorded reduced intergravel oxygen values after logging (10, 19, 35). The increased fines, by filling gravel interstices, reduced the exchange of oxygen-rich surface water with oxygen-deficient water within the gravel bed. In addition, the increased organics in the bed consumed oxygen at a greater rate (11, 36). Oxygen requirements and consumption for chum salmon are highest about the time of hatching, and the minimum level of dissolved oxygen necessary for normal development lower after active respiration across gill membranes begins (12, 36, 37). Maximum levels would be required during the postspawning period, which appeared least affected by logging (Fig. 6). Postspawning intergravel oxygen concentrations prior to 1978 were normally distributed about a mean of

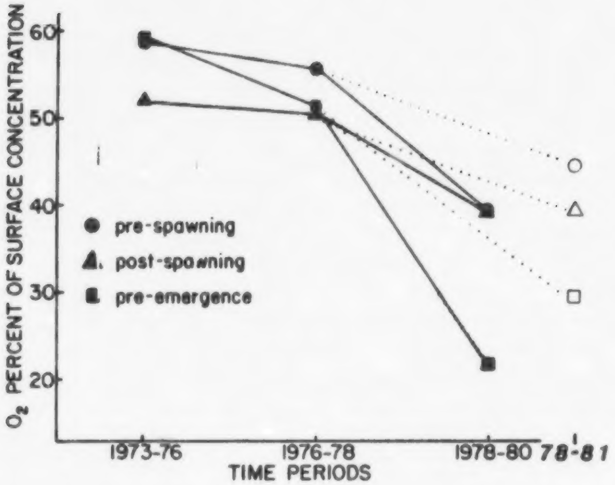

Fig. 6. Carnation Creek mean intergravel dissolved oxygen values expressed as a percent of surface concentration for prespawning, postspawning, and prefry emergence sampling periods. Time periods shown are January 1973 to August 1976, September 1976 to October 1978, and November 1978 to August 1980. The means of the November 1978 to September 1981 time period are presented as light characters connected by dotted lines.

6.3 mg/L (12.6 mg/L x 49.7%). Still 5% of the samples were below 2.5 mg/L (12.6 mg/L x 20%). Therefore, most sites sampled probably had adequate oxygen levels for normal development prior to 1978 (12). However, after November 1978, the postspawning intergravel oxygen mean concentration was 3.2 mg/L (Fig. 6, 39%, 8.25 mg/L mean surface concentration), but concentrations were not normally distributed. They were skewed towards lower values; therefore, more sites had concentrations below than above 3.2 mg/L. It is highly probable that chum salmon at many sites would be developing in an oxygen-deficient environment.

Subgravel Permeability In Study Section I

As the delivery rate of oxygen to an incubating salmon egg is a function of velocity, as well as oxygen content of the water, intergravel velocities (centimetres per hour) were also obtained from Section I (12). A total of 990 readings were taken between January 1973 and April 1980 and a wide range of values around a mean of 5940 cm/h were obtained. Permeability was compared for the three time periods (January 1973 to August 1976, September 1976 to October 1978, November 1978 to August 1980) and for the three seasons (prespawning, postspawning, and prefry emergence). The difference among time periods ($F = 7.91^{***}$) and the interaction between times and seasons ($F = 4.92^{***}$) were significant, but the difference among seasons was not significant ($F = 1.94$, 0.14). Permeability was lower after the November 1978 freshet than during the two previous time periods. This appeared to result from the very low values which were obtained during the preemergence season (Fig. 7).

Few recent changes were apparent when another 180 permeability measurements were included in the second analysis. After the November 1978 freshet, permeabilities were still lower than during either the prelogging or prefreshet time periods ($F = 35.4^{***}$, $F = 17.2^{***}$) and mean permeabilities for the prespawning and preemergence seasons were not changed by this new data (Fig. 7). Only postspawning permeabilities appeared to be greater (Fig. 7).

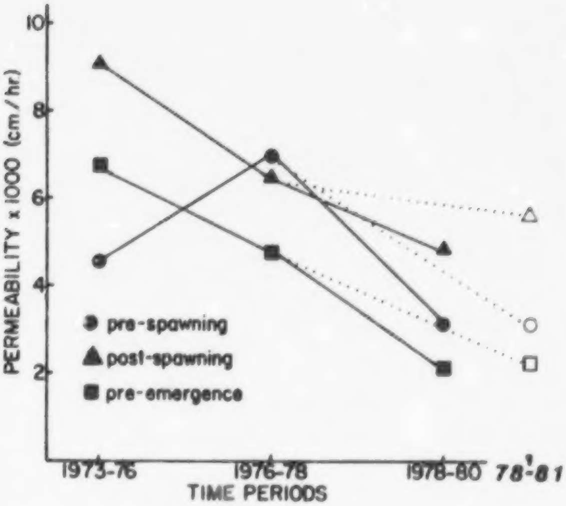

Fig. 7. Carnation Creek mean intergravel permeabilities from prespawning, postspawning, and prefry emergence samplings for time periods January 1973 to August 1976, September 1976 to October 1978, and November 1978 to August 1980. The means of the November 1978 to September 1981 time period are presented as light characters connected by dotted lines.

W.P. Wickett noted that permeabilities were related to chum salmon survival at several spawning sites in British Columbia (Fig. 8). Survival was dramatically reduced when permeabilities fell below 3000 cm/h. Postspawning and prefry emergence permeabilities were normally distributed around means of 6800 to 9000 cm/h (Fig. 7). After November 1978, the Carnation Creek results were skewed in a Poisson-like distribution below means of 2150 and 4850 cm/h. Clearly, the permeabilities of many sites in Section I were below 3000 cm/h, thereby potentially reducing chum egg-to-fry survival (Fig. 8).

Accumulation of sand and pea gravel in the top layer of the bed since November 1978 would appear to have filled the spaces between the gravel and reduced the velocity of interstitial water. Exchange rates between surface and intergravel water would also appear to have been reduced, resulting in lower concentrations of subsurface-dissolved oxygen. The presence of sand in the bed is known to be inversely related to the fitness and survival of incubating chum eggs (8, 13, 36), while oxygen concentration and permeability are directly related to fitness and survival (8, 11, 12, 13).

Gravel Composition In Study Sections II to IX

In Sections II to IX, sampling was less intensive. It was done once a year to determine gross changes to the substrate composition. Generally, if an area is to be sampled only once per year, the literature suggests sampling during low flow when the bed is always relatively stable (23, 24).

The 392 cores which were split into top and bottom layers were compared between depths and among the three time periods (prelogging, January 1973 to August 1976; postlogging, September 1976 to October 1978; postfreshet, November 1978 to August 1980) for all five classes of fines. Fines of all particle-size classes were significantly greater in the bottom layer than the top layer (Table 2). Significant differences among time periods were obtained for particles less than 9.55 mm and 0.074 mm. Since the layers were so distinctly different, analyses were completed only on the top layer in which eggs incubate.

Top-layer subsamples were compared for the three time periods and the four streamside treatment

Table 2. F statistics from analyses of variance on percent fines less than 9.55, 2.38, 1.19, 0.297, and 0.074 mm from Carnation Creek gravel cores in Sections II through IX. NS = not sign., * = sign. 0.05, ** = sign. 0.01, *** = sign. 0.001. Means are shown in Figures 9, 10, and 11.

Analysis	No. of Samples	< 9.55 mm	< 2.38 mm	< 1.19 mm	< 0.297 mm	< 0.074 mm
Two-way ANOVA:	782					
Depth (i)		10.4***	26.1***	28.3***	46.9***	27.4***
Time periods (ii)		3.1*	1.5 NS	0.1 NS	0.1 NS	3.1*
Interaction		0.6 NS	1.0 NS	1.6 NS	0.4 NS	0.2 NS
Two-way ANOVA (top layer):	391					
Time periods		3.4*	3.1*	2.1 NS	0.2 NS	1.5 NS
Area		4.0**	3.0*	2.8*	3.9**	5.8***
Interaction		1.5 NS	1.6 NS	1.8 NS	2.0 NS	1.9 NS
One-way ANOVA (top layer):						
Area 1 – Time periods (iii)	148	5.0**	4.4*	3.8*	2.0 NS	0.2 NS
– Pairwise tests		$(1 \approx 2) < 3$	$(1 \approx 2) < 3$	$(1 \approx 2) < 3$		
Area 2 – Time periods	104	1.1 NS	1.0 NS	0.7 NS	0.5 NS	0.2 NS
Area 3 – Time periods	81	0.7 NS	1.6 NS	0.8 NS	0.1 NS	0.8 NS
Area 4 – Time periods	58	3.4*	3.8*	3.2*	1.7 NS	1.3 NS
– Pairwise tests		$1 > (2 \approx 3)$	$1 > (2 \approx 3)$	$1 > (2 \approx 3)$		

(i) Depth:
1. Top layer
2. Bottom layer

(ii) Time periods:
1. January 1973 to August 1976
2. September 1976 to October 1978
3. November 1978 to August 1980

(iii) Areas:
1. Sections II, III, and IV
2. Sections V and VI
3. Sections VII and VIII
4. Section IX

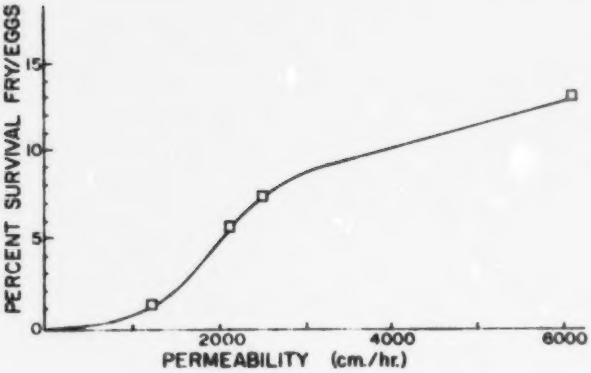

Fig. 8. Relationship between percent egg-to-fry survival and geometric mean permeability from Nile, Hooknose, and McClinton creeks, British Columbia (from W.P. Wickett).

areas (Area 1, Sections II to IV; Area 2, Sections V to VI; Area 3, Sections VII to VIII; Area 4, Section IX) for all five classes of fines. Areas were significantly different for all particle-size classes (Table 2). Significant difference between time periods was obtained only for fine particles less than 9.55 mm and 2.38 mm. Since areas were significantly different, time periods were compared for each area independently (Table 2). Area 1 and Area 4 showed significant differences among time periods for fines less than 9.55, 2.38, and 1.19 mm. Differences in Area 1 were the result of increased fines in 1979-1980 (Figs. 9 and 10). Since no increase in fines smaller than 0.297 mm was apparent (Fig. 11), coarse sand, medium sand, and pea gravel had accumulated in the top layer of the bed after the November 1978 freshet (Figs. 9 and 10). This material was probably transported downstream from Area 2 where considerable bank erosion had occurred (31, 38).

Area 2 received the most intense streamside logging treatment. Percent fines less than 9.55 mm increased by 4% during the study, but sample size was too small and the variance between cores too high for these differences to be significant (Fig. 9).

Area 3 was either bordering or upstream of the 1976-1977 logging activity and it was logged after the November 1978 freshet (1978-1979). Mean percent fines less than 9.55 mm decreased 3% during the time that Areas 1 and 2 were being influenced by logging (Fig. 9). Percent fines increased again after the area was logged. Neither observation was statistically significant (Table 2).

Significant declines in fines were observed in Area 4. Mean percent fines less than 9.55, 2.38, and 1.19 mm decreased 9, 5, and 2%, respectively, after 1973-1976 (Figs. 9 and 10). No significant changes were observed for smaller particles (Table 2, Fig. 11). This cleaning of the top layer could have been the result of scouring which occurred during the February 1977 freshet. Fines increased by 7% and 2% during 1979-1980 for particles less than 9.56 mm and 2.38 mm, respectively, but neither increase was significant (Figs. 9 and 10). Only 16 processed samples from 1979-1980 were available for this analysis.

As a result of logging during the winter of 1976-1977, the streambanks of Area 2 were extensively eroded during the November 1978 freshet (38). This produced accumulations of coarse and medium sands and pea gravel in top layers of the bed in all sections downstream of the intense logging treatment. The bed in upstream areas was either unchanged or showed the effects of scouring which cleaned the gravel of fine particles.

Fry Production Upstream of the Counting Fence

Annually, 250 coho and approximately 10% of the chum salmon run spawned above the fish-counting

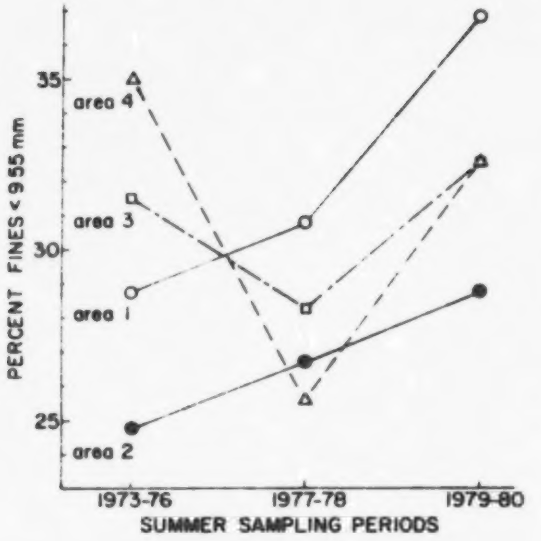

Fig. 9. Mean percent of particles less than 9.55 mm from the top layer of streambed cores from Sections II to IX of Carnation Creek. Time periods include cores from the summers of 1973 to 1976, 1977, and 1978, and 1979 and 1980 (Area 1, Sections II to IV; Area 2, Sections V and VI; Area 3, Sections VII and VIII; Area 4, Section IX).

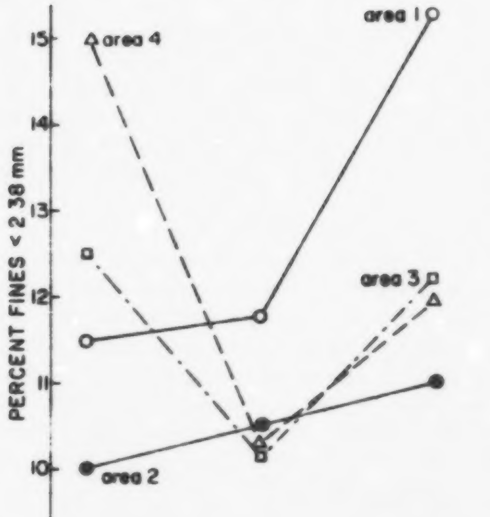

Fig. 10. Mean percent of particles less than 2.38 mm in the top layer of streambed cores from Area 1 (Sections II to IV), Area 2 (Sections V to VI), Area 3 (Sections VII to VIII), and Area 4 (Section IX) of Carnation Creek. Years represent periods of prelogging, post-logging, and post-November 1978 freshet.

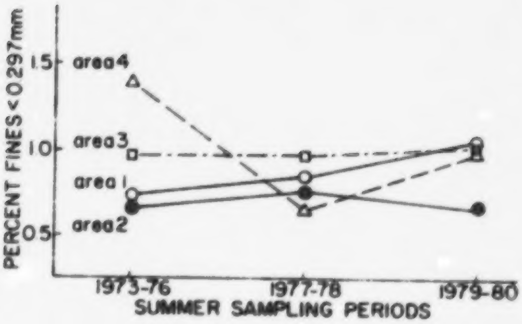

Fig. 11. Mean percent of particles less than 0.297 mm in the top layer of streambed cores from Area 1 (Sections II to IV), Area 2 (Sections V to VI), Area 3 (Sections VII to VIII), and Area 4 (Section IX) of Carnation Creek Years represent periods of prelogging, postlogging, and post-November 1978 freshet.

fence (Fig. 1). Potential egg deposition was obtained by using egg-to-length correlations and the number of females in the different size categories (39, 40). Emigrating chum and coho fry migrating through the fence in the spring were counted and subsamples of chum fry were measured for condition. Percent chum salmon survival from potential egg deposition to migrating fry was calculated each year. Similar survival percentages were calculated for coho from the sum of May fry population estimates and fry counts at the fence prior to the population estimates (41, 42, 43, 44).

During the prelogging period, chum survival varied between 16% and 25% (Fig. 12). This range was similar to or higher than survival estimates from other natural systems (13, 36, Fig. 8). Survival increased during the springs of 1977 and 1978 to 27% and 30%, respectively (Fig. 12). These high egg-to-fry survivals could likely be related to the relatively stable flows that occurred through the incubation period during these years. After the November 1978 freshet, survival estimates declined to a range of 5% to 24% (Fig. 12). The probability that this was due to chance alone was 0.08 (Mann-Whitney U-test; 45).

The pattern of coho egg-to-fry survival was similar. Estimates ranged between 23% and 37% during prelogging years, declined to 26% during the winter of the intense logging treatment, and then increased to 41% during 1977-1978 when flows were very stable (Fig. 12). After the November 1978 freshet, survival declined to a range of 11% to 28%. The probability of the prefreshet range being identical to the one after it was 0.02 (Mann-Whitney U-test). This probability was obtained by considering the survival estimate for 1979 higher than the one for 1974, even though they were identical (28%, Fig. 12).

Clearly, salmon egg-to-fry survival has been affected by accumulations of fines in the streambed and/or by the accelerated bedload transported during changes to the channel.

CONCLUSIONS

1. The gravels in Section I of Carnation Creek are similar to or cleaner than the lower reaches of other well-studied Pacific Northwest streams.
2. Fines less than 9.55 mm increased with gravel depth.
3. In the top and middle layers, fine sands, silts, and clays exhibited a seasonal trend, decreasing between autumn (prespawning) and spring (preemergence) and increasing through the summer period.
4. In the top layer, pea gravel and sands increased after the first major postlogging freshet (November 1978) in the lower 2 km of stream.

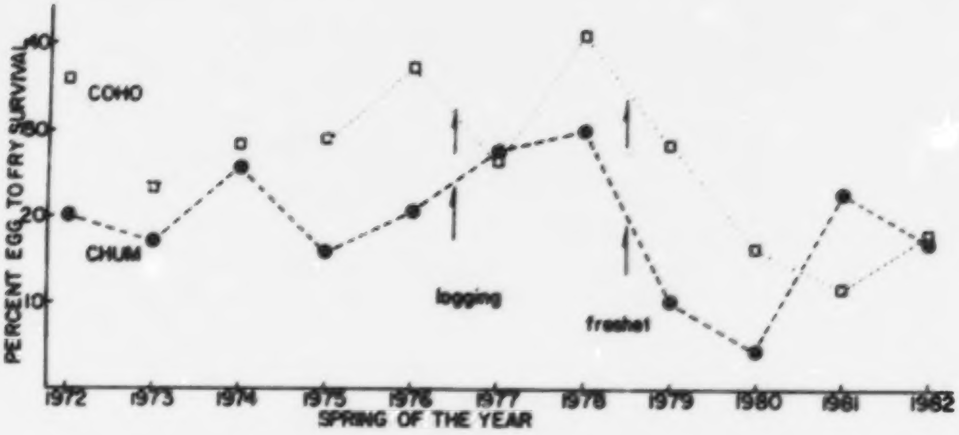

Fig. 12. Chum and coho salmon egg-to-fry survivals above the Carnation Creek fish-counting fence are shown for 1972 to 1982. The intense streamside logging and November 1978 freshet are indicated.

5. The middle layer exhibited an increase in fines between 9.55 mm and 0.297 mm after August 1980.

6. In the bottom layer, classes of fines less than 0.297 mm declined after the first major postlogging freshet (November 1978).

7. Between August and September 1980, gravel quality was still continuing to decline in Study Section I.

8. Surface and intergravel-dissolved oxygen levels exhibited a seasonal trend of increasing through the incubation period.

9. Intergravel-dissolved oxygen levels declined for all seasons after the first major postlogging freshet (November 1978).

10. Intergravel permeability declined after the first major postlogging freshet (November 1978) and current levels at many more sites are below threshold levels cited in the literature as limiting chum fry production.

11. Pea gravel and coarse and medium sands increased in the top layer of all study sections downstream of the area where timber was felled into the stream and removed, while upstream quantities of these fines declined or were unchanged.

12. Chum and coho egg-to-fry survival upstream of the fence have dramatically declined from prelogging levels.

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QUESTIONS
TO M. BROWNLEE

Question *(B. Tassone)*: You were talking about bedload here, I took the liberty of making some estimates of the bedload transported, based on the volume that moved past B-weir, i.e., based on the volume that moved, shown on one of the visual aids. It showed that bedload was of the greatest part of the total sediment load.

Answer *(M. Brownlee)*: Yes. Now, one of the things I should mention is that, while we have talked about changes to different size fractions within a gravel core and then at the end of that I offered a comment on egg-to-fry survival, it almost implicitly suggests a function of sedimentation on egg-to-fry survival. I do think that is one particular aspect. More importantly, and I think that it will be particularly evident tomorrow when you start looking at different slides within the stream, that much of that channel of Carnation has destabilized and that bedload is very active. The bottom line of this is that we start looking at the quantities of material that are passing B-weir.

Answer *(B. Tassone)*: That's based on the what's been trapped at B-weir or removed by your small cat at B-weir. Those estimates are probably conservative estimates of what has been left behind. There has been a considerable amount of material flushed through the weir. We say the bedload makes up probably at least 70% or 80% of the total sediment load, which is a combination of bedload and sediment.

Answer *(M. Brownlee)*: Yes. The bedload is extremely active in Carnation Creek. You can imagine that, since freshets are often coincidental to the incubation period regarding anadromous fish which come in and utilize gravel by placing their eggs in such areas, such eggs are going to be vulnerable. Think of the effects that this gravel movement would have on the incubation success. The effects start to become evident.

Question *(Unidentified)*: Mike, one of your graphs there indicated that the average of fry survival appears to be coming down in recent years. Is there any indication of the quality of those fry?

Answer *(M. Brownlee)*: No, we just looked at one of the things that we were doing in regard to fry condition. If I could speak about the chum for a moment, we had some of the data summarized on this point. From a very preliminary look, it looks like the K-factor, so far, is constant. The condition, the length and weight relationship, you would think would vary depending on length in the gravel. But condition hasn't changed very much among the chum. But that's got to be worked out over duration. We have to look at how long those fry are emerging, i.e., are they emerging over a longer period than they would if they had been incubating in a better site? Regarding the coho fry, I'm not sure that they've looked at length-weight relationship of those fry that pass through the fence.

Further Answer *(B. Holtby)*: We recently have looked, in a preliminary way, at the condition of the coho fry at the fence. It is a difficult thing to do because we don't have fry as they emerge, rather we have them as they appear later at the fence. So things can change, their weight can decrease or increase.

Comment *(M. Brownlee)*: So it would be a hard thing to analyze because you have fry that are being displaced from the stream and they're not the ones that are actively rearing, which indeed might be in a lot better condition.

Comment *(B. Holtby)*: Well, if you make the assumption that all things are constant over time, their condition is decreasing in recent years, they're becoming lighter.

Question *(Unidentified)*: You mentioned that water temperature was an advantage to the fry. Water temperature was coming up after logging. I was wondering if you could clarify that?

Answer *(B. Holtby)*: I'll be talking about that in a little more detail tomorrow if you could wait.

Question *(D Handley)*: Mike, you pointed to some changes in the gravel composition there. Can you speculate on what the significance of those changes really are?

Answer *(M. Brownlee)*: Until we have a chance to look at the condition of the fry in the chum area for example, in some meaningful way, it will be very hard to say what has happened there. If we look at what's happened above the fence, where there's been some decrease in survival, I think that it is more related to bedload movement than sedimentation. However, that's a pretty cursory observation. We know that this is happening because, when you're out there in the winter and watching the gravel move like hell, you think that must be more of a problem than any sedimentation. Even though we are looking at some increases in the sand component of the gravel, we're still looking at gravel that is relatively clean. However, the fish are responding negatively to the changes. It would seem they are doing so in quite a dramatic way. Is that particular phase of egg-to-fry development so sensitive that only a very fine contribution of the sand-sized particles, such as the cones we're noting the increase in (as opposed to the very fine clay silt fractions that have been noted in other studies, e.g., the Alsea Study), causing the changes? Until we have a chance to look at that, it's going to be difficult to comment more.

Question *(Unidentified)*: Mike, I think you've shown some data suggesting a decrease in permeability over time. (Yes.) Can you relate the changes in permeability to any of your changes in sediment composition?

Answer *(M. Brownlee)*: We have not found any correlation. This is one of the first things you ask the "data-whiz kids". Is there any correlation between fines and dissolved oxygen?, between permeability and fines?, and between D.O. and permeability? Surprisingly, while we went into this expecting there would be correlations, it's just been a scatter. So, at this point, there isn't anything that's that obvious. Whether it's because we are at the cleaner end of the spectrum as far as the sands and fines are concerned, even though we are noting dramatic reductions in dissolved oxygen and some rather dramatic changes in permeability, there still doesn't seem to be the quantity of fines or the amount of material there that would have any negative effect. So, possibly if we looked at the extreme condition, we might see more correlation. But certainly, permeability has moved to a level where P. Wickett noted results in his work that make us anticipate that the egg-to-fry survival would be reduced. However, I don't know whether that's what's causing the problem. It's a bit early to point to it yet.

Comment *(C. Scrivener)*: The problem is that part of this has been plotted from egg survival means. The last set of analysis that we've been required to look at involves the change in specific sites and the quality of specific sites. It looks as if a number of sites have deteriorated markedly. However, we still have another 45 sites, a few of them that are as good as they ever were with the same composition. Maybe you could start looking at the sites that have changed the most dramatically and start relating permeability and oxygen on both sites with changing gravel quality—then we might see something.

Answer *(M. Brownlee)*: We haven't had a chance to stratify yet, to look at new aspects.

Question *(J. Cederholm)*: Mike, I'm a little confused in regards to the influence of the counting fence in the bedload movement. And the way I understand it, from what you've presented, is that the counting fence is interrupting the bedload movement and is causing deposition above it.

Answer *(M. Brownlee)*: Yes.

Question *(J. Cederholm)*: Along the same lines, I was wondering what influence that would have on the area you are so intensively sampling below the weir.

Answer *(M. Brownlee)*: Well, that's a good question because that's something we discussed with Dave Narver and Al Lill at the time the fence was built. I think it has influenced that piece of gravel and I think it may have influenced the regime and the kinds of material that would pass that fence if it wasn't there.

Question *(J. Cederholm)*: If I continue that line of thinking and then in conjunction with the fact that you're removing a substantial number of samples from the area below the weir and that you're noticing this tremendous variability in your relationships, I would suggest that the weir is probably confounding your results from the sampling area below it.

Answer *(M. Brownlee)*: Yes, it is. It certainly is. The rationale that we used, however, was that we had 3 years or 4 years of work below the fence prior to logging. If we left that area to go upstream, there would be problems because most of the chum spawners were utilizing the reach below the fence. We thought that it might still be most useful to continue with a detailed effort below the fence.

Question *(Unidentified)*: I was wondering how you determine your egg-to-fry survival for the chum.

Answer *(M. Brownlee)*: For chum we do it by looking at length of the females, egg number vs. length of females, and, hence, potential deposition. We then look at number of fry downstream. This is for calculations upstream of the fence. We're not looking at egg numbers and survival below the fence. Downstream of the fence, we're looking at fry condition. It's very difficult to get survival data without using hydraulic samplers. This would be disruptive to that gravel environment. Therefore, we thought we would continue to use the K-factor to look at the condition of those fry that were emerging below the fence. It is a biological indicator of the physical changes that are occurring below the fence.

Comment *(C. Scrivener)*: One thing I would mention about the fence and the amount of bedload held up there is that the proportion that's deposited around that fence, as a fraction of the total bedload moving system, is very small. The influence of that fence may not be as great as you first anticipated.

Comment *(J. Cederholm)*: However, the intergravel area and the intertidal areas are quite dynamic substrate environments. Something, such as a weir, that interrupts this interplay and this movement of particle and sorting could have a strong influence on the quality of gravel and the area downstream, if it's being interrupted in such a manner.

Comment *(J.C. Scrivener)*: There's certainly something there but there's one thing that Mike didn't show. He showed the fine-sand and smaller-than-fine-sand fractions as undergoing an insignificant statistical increase. But if you look at it on the three sample periods, you find there's an annual cycle in particles fine sand and smaller, so that there's still some mixing going on in that estuary; the very fine fraction of the sand is actually being removed on an annual basis. It builds up over the summer. It's highest values are attained in the prespawning period. The lowest values are attained in the preemergence period after the winter and after the area has been influenced by winter freshets.

Question *(Unidentified)*: Regarding variability between your samples from the bottom of the stream to the top, in any one sampling period, were there statistically significant differences, upstream and downstream, through your sites? Or was composition the same along the stream? Could you compare the sites or were they all different? Were any two sites similar up and down the linear length of the channel? The reason I'm asking is we've got this problem in our data in Queen Charlotte Island work.

Answer *(C. Scrivener)*: Certainly, toward the upper section, Section 9, towards the top, is a bit different. In the lower sections, the gradient is fairly similar. As you look at the upper section, certainly you're approaching a cobble-bottom situation.

Comment *(M. Brownlee)*: It seems to me you're asking, Is there a consistency in terms of the results we're getting from sampling certain locations, by section of stream?

Question *(Unidentified)*: No, I am asking, Is Section 2 the same as Section 3, the same as Section 4, when you sample in the middle of summer within the same sampling period? Are they the same type of gravel or is there definitely a difference?

Answer *(M. Brownlee)*: No, there's variability, but particularly from the upstream location to the downstream area. It's a function of gradient and a number of other things, I'm sure you're well aware. But there's predictability, I think, to a certain point, as to what we'll find there.

Question *(Unidentified)*: There has been particular concern for chum survival, particularly regarding potential for fry to survive in the estuary. Has there been any notable change in emergence timing due to either sediment or temperature effects?

Answer *(M. Brownlee)*: Well that's what we want to look at now and that's why I hope to have the data worked out for this session, because we haven't really talked about the fry in the area. We presented gravel and dissolved oxygen results. Unfortunately, we didn't get a chance to look at emergence timing.

THE EFFECT
OF EXPOSURE TO SHORT-TERM PULSES OF SUSPENDED SEDIMENT ON THE BEHAVIOR OF JUVENILE SALMONIDS

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ABSTRACT

The behavior of juvenile coho salmon (*Oncorhynchus kisutch*), in response to exposure to short-term pulses of suspended sediment, was monitored in a laboratory donut channel. Results indicate a breakdown of social organization, a change in the form of aggression elicited, an increase in activity, and a decrease in feeding ability in response to suspended sediment. The data suggest the potential for decreased fish production in streams affected by short-term pulses of suspended sediment.

INTRODUCTION

Exposure to suspended sediment can produce a number of adverse effects on fish. The effects of chronic exposure to suspended sediment are well documented. Blood physiology indicators suggest that stress occurs in salmonid fry held in sublethal concentrations of suspended sediment (Noggle 1977; Sigler 1980). Damage to gills often results (Herbert and Merkens 1961; Noggle 1977; Sigler 1980) by interfering with normal respiratory processes (Kramer and Smith 1965). Feeding ability is decreased (Bachmann 1955, Gardner 1981; Moore and Moore 1976; Noggle 1977; Olsen et al. 1973; Sigler 1980; Vinyard and O'Brien 1976). Behavioral studies indicate a preference by coho for areas of low turbidity, but avoidance at higher turbidities (Noggle 1977). The synergistic actions of the abovementioned stresses may manifest themselves by depressing growth rates of fish in turbid water (Bjornn et al. 1977; Buck 1956; Crouse et al. 1981; Noggle 1977; Saunders and Smith 1965; Sigler 1980; Swenson and Matson 1976) and/or survival (Campbell 1954; Herbert and Merkens 1961; Noggle 1977; Sigler 1980; Wallen 1951).

Recent activities of man in watersheds of rivers and streams often result in periodic short-term pulses of suspended sediment. The nature of these pulses suggest that attention should perhaps be shifted away from the static bioassay studies as have so often been performed and focussed more on the effects of frequent exposure to short-term pulses of suspended sediment on fish.

The objective of this study was to determine if exposure to short-term pulses of suspended sediment produces any alterations in the behavior of juvenile coho salmon. The study is being performed in conjunction with the Carnation Creek Watershed project, evaluating the impact of logging on fisheries resources.

METHODS

Source of Test Fish

Underyearling coho salmon were utilized in the study. Coho rear in fresh water for approximately one year before migrating to the sea. Coho are, therefore, more likely to be affected by alterations to their environment induced either naturally or by man than are species such as pink salmon (*Oncorhynchus gorbuscha*), which migrate to the ocean shortly after emergence.

Coho were obtained from a population of Chilliwack River fish. Eggs were taken from adult coho on their spawning run, artificially inseminated, and reared in the laboratory in order to eliminate any learning effect which may be associated with prior experience with suspended sediment.

Holding Conditions

Shortly following emergence (July 1981), approximately 400 juvenile coho were placed in two 250 L fiberglass oval tanks. Water temperature was maintained near 10.0°C ± 0.5°C, with the use of a refrigeration unit. Oxygen levels were maintained near saturation with airstones and pumps. Light was controlled by a timer without a dimmer on a photoperiod simulating the natural day length. The fish were fed twice daily in excess with Tetra-myn, once in the morning and once in the late afternoon.

Experimental Channel

The effects of short-term exposure to suspended sediment were studied in a donut channel constructed of plexiglass (Fig. 1). A refrigeration unit was placed in the centre of the channel to maintain the water in the arms of the channel at a temperature of 10.0°C ± 0.5°C. A pump placed in the channel produced a flow of 7 cm/sec. In the arm of the channel used for behavioral observations, cobbles and gravel were placed on the bottom. The second arm used for feeding experiments was not lined with any materials in order to minimize eddies which might otherwise interfere with the passage of introduced prey items. Oxygen was kept at near saturation levels with airstones. A photoperiod simulating the natural day length was employed. Water depth was 25 cm.

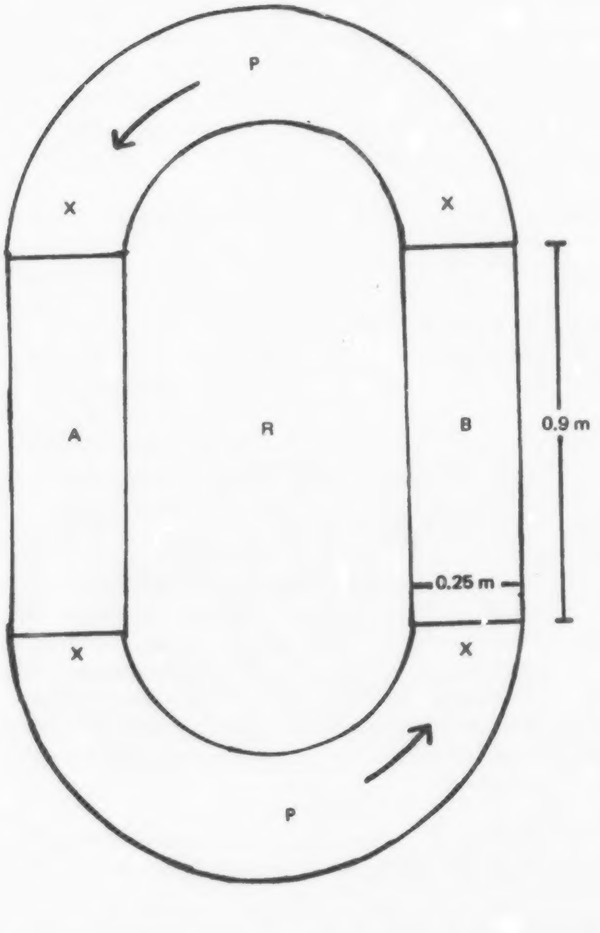


Fig. 1. Generalized schematic of stream channel used in study:

A = arm used for feeding experiments;
B = arm used for behavioral observations;
P = pump;
R = refrigeration unit;
X = sampling points for suspended sediment analysis;
↗ = direction of water flow.

Sediment Source

Turbidity was created by the addition of a slurry of bentonite clay to the channel. The slurry was prepared two days preceding the scheduled introduction of suspended sediment to the tank by mixing bentonite clay in water, allowing it to settle over each of two consecutive nights, and decanting the suspended slurry on each day. The slurry was then added to the donut channel to the desired turbidity with the use of a pump equipped with a valve.

Turbidity was determined with a DRT-150 Turbidimeter and measured in the optically accepted nephelometric turbidity units (NTU). Water samples were collected at three depths (0, 10, and 20 cm) at selected points (Fig. 1) and an average turbidity value was determined.

Experimental Procedure

The experimental design consisted of a repeated exposure of juvenile coho to a short-term pulse of suspended sediment (Fig. 2). Experiment "Xa" refers to the first exposure, "Xb" to the second, "X" referring to either the first experiment (X = 1) or the second replicate experiment (X = 2).

In experiment 1, 10 fish (mean length = 7.4 cm, range = 6.8 cm to 8.1 cm; mean weight = 4.00 g,

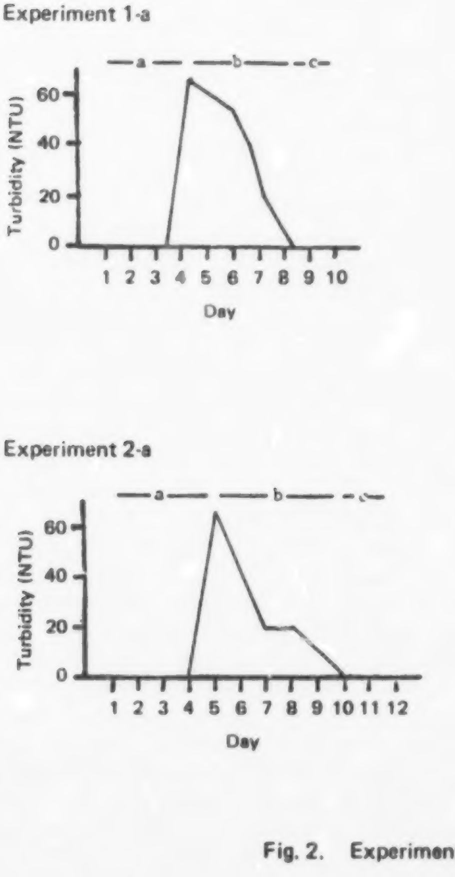


Fig. 2. Experimental design:

a = pretreatment phase;
b = treatment phase;
c = posttreatment phase.

range = 3.22 g to 5.71 g) were placed in each arm of the donut channel for behavioral and feeding studies (Fig. 1). Fish were allowed to acclimatize for a period of 6 days, prior to the commencement of the experiment. The fish were observed in clear water for a period of 3.5 days. This phase of the experiment will be referred to as the "pretreatment phase". A slurry of suspended sediment was then added to a concentration of 60 NTU and continued for 3 days, representing a pulse of suspended sediment. Turbidity was maintained with the use of airstones, recirculating pumps, hand stirring, and the occasional addition of small amounts of slurry. On the morning of the seventh day, the channel was partially flushed with clear water, reducing the turbidity to 20 NTU. The tank was again flushed on the evening of the seventh day and the afternoon of the eighth day, further reducing the turbidity to 10 NTU and 0 NTU, respectively. The suspended sediment phase (10 NTU to 60 NTU) will be referred to as the "treatment phase". The phase following 0 NTU will be referred to as the "posttreatment phase" and spanned a period of 3 days. Following the termination of experiment 1-a, the fish were temporarily removed and the tank thoroughly cleaned. The fish were allowed to reacclimatize for a period of 3 days, at which time experiment 1-b, representing the second exposure to suspended sediment, commenced. Observations were made at pretreatment conditions for 2.5 days. A pulse of sediment was added on the afternoon of the third day to a turbidity of 60 NTU and maintained for 1.5 days. On day 5, the tank was flushed, reducing the turbidity to 20 NTU. On the evening of day 6, turbidity was reduced to 10 NTU and on the evening of day 7, turbidity was further reduced to a posttreatment condition which continued for 3 days. The end of the latter phase marked the completion of experiment 1-b and, hence, experiment 1.

A replicate experiment (experiment 2) was conducted 2 weeks later using a new group of fish (mean length = 7.2 cm, range = 6.7 cm to 7.7 cm; mean weight = 3.3 g, range = 2.5 g to 4.4 g). The experimental procedure followed a similar format as experiment 1 (i.e., experiment 2-a and experiment 2-b), with only slight modifications (Fig. 2). After a 6-day acclimitization period, observations were made at pretreatment conditions for 4 days. On day 5, a sediment pulse was added and maintained at 60 NTU for 2 days. On day 7, the channel was partially flushed, producing a turbidity of 20 NTU for 2 days. On the evenings of days 8 and 9, the channel was again flushed, allowing observations at 10 NTU and 0 NTU, respectively. The posttreatment phase was maintained for 3 days and also served as the pretreatment phase for experiment 2-b, utilizing the same fish. The 60 NTU treatment phase spanned 1.5 days; the 20 NTU and 10 NTU treatment phases, both 1 day. The posttreatment phase was 1.5 days long, marking the termination of experiment 2.

Throughout both experiments, fish in the behavioral arm were observed for a total of 45 minutes at least once a day and, in most cases, twice a day. Morning observations were made between 08:00 and 10:00 (lights being turned on at 07:00), and afternoon observations were made between 14:00 and 16:00. Observations were made for 15 minutes prior to the addition of a pulse of food (Tetra-myn), the food remaining in the water flow for approximately 5 minutes and then for 25 minutes following the addition of the food. During each 45-minute observational period, the following observations were made:

1. Position. The three-dimensional position of each fish was recorded at 5-minute intervals. Position was determined with the use of a grid dividing the observational arm into 9 cm to 10 cm long sections (sections A to I) and 5 cm to 5 cm deep strata (stratum 1 representing the top 5 cm and stratum 5 representing the bottom 5 cm). Positions across the width of the tank were noted as left, left centre, centre, right centre, and right.

2. Intraspecific Behavior. Qualitative and quantitative information on behavioral interactions between fish were summated and recorded over 5-minute intervals. The behaviors used in the statistical analysis were those which could be clearly observed and identified under high turbidity levels (60 NTU), i.e., lateral displays, threats, and nipping (actual nipping and attempted nipping), as defined by Hartman (1965). Chasing was combined with threats, as it was not always easy to see if a threat terminated in a chase. In the analysis of the intraspecific behavior data, the frequency of a behavior observed during each 5-minute interval was divided by the number of fish observed at the end of each 5-minute observational period.

3. **Territoriality.** The number of fish showing territorial behavior, as defined by Kalleberg (1965), was recorded. Fish were first considered to be territorial when they actively defended a position throughout an observation period and were confirmed as territorial when the same position was defended by the same fish for 2 observational periods. Parr mark patterns allowed identification of individual fish.

4. **Activity.** This variable was determined subjectively by noting the preponderance of:

   a. Positional fish: defined as those fish maintaining a position(s) for longer durations throughout each 5-minute observational period, with or without the defence of the position.

   b. Swimmers: defined as those fish who either did not maintain, or maintained for only a very short period of time (less than 1 minute), a position; exhibiting instead a more active swimming behavior.

   Quantitative analysis was attempted in the second phase of experiment 1, comparing the frequency of movement of fish past the midpoint of the observational arm for 5-minute intervals at each turbidity level.

5. **Feeding.** The ability of fish to feed on drifting prey in turbid water was observed in a series of experiments conducted in the second arm of the donut channel. Twenty-five prey items (freeze-killed *Drosophila*) were added individually on the water surface. The prey were allowed to pass the fish one at a time at a rate of 7 cm/sec and collected downstream in a net. The total number of prey consumed per trial was recorded along with number of misstrikes per prey item. The response times of the fish to the addition of the pulse of food which was added during the behavioral observations, measured as the time from the addition of the food to the time when one fish detected the food, was also recorded.

6. **Coughing.** The physiological response of fish to suspended sediment was noted by recording the frequency of coughing, recognized by the pronounced flaring of the gills, within each 5-minute interval.

RESULTS AND DISCUSSION

Position

Turbidity had a marked effect on the vertical distribution of fish (Table 1, a to d). Prior to a sediment pulse (0 NTU), a significantly greater proportion of fish were located in the water column (strata 1 to 3, p = 0.05). This trend was found in all 4 pretreatment phases (experiments 1-a and 1-b; experiments 2-a and 2-b). Within 4 hours of the addition of suspended sediment (turbidity equal to 60 NTU), fish became closely associated with the bottom substrate (strata 4 to 5), showing a significant depression of their vertical distribution (p = 0.05). As turbidity declined to 20 NTU, a significant increase (p = 0.05) in the frequency of fish observed in the water column was noted in 3 of 4 cases. A reduction in turbidity to 10 NTU resulted in a further increase in frequency of fish in the water column, significantly different from the vertical distribution at 20 NTU in 2 of 4 cases (p = 0.05). Fish were mostly associated with the water column throughout the posttreatment phase, but distribution differed significantly from that at 10 NTU only in experiment 1-a (p = 0.05).

Prior experience with suspended sediment did not alter the behavioral response in vertical distribution of the fish. A similar trend was noted following the repeated exposure, although some differences were noted; these are, however, attributable to differences in the behavior of individual fish in each experimental group.

These results suggest that the vertical distribution of fish in a water column is affected by suspended sediment and that their position is, in part, dependent upon the ability of fish to use visual cues as reference points. In the pre- and posttreatment phases, visibility in the channel was high, allowing the fish to orient and maintain positions using the characteristics of both the bottom substrate and the side walls of the channel as reference points. At a turbidity of 60 NTU, photopic vision was restricted to approximately 5 cm to 10 cm for the human eye. The bottom substrate could not be seen from the upper strata by the fish (inferred from the distance at which fish became startled upon the detection of another fish). Therefore, the maintenance of a position in the upper

Table 1. Frequency (%) of fish in water column (strata 1 to 3) and associated with the bottom substrate (strata 4 to 5) in response to suspended sediment concentration.

Experiment 1-a

	Turbidity (NTU)				
Strata	0	60	20	10	0
1 to 3	80.2	53.6	75.4	69.6	41.8
4 to 5	19.8	46.4	24.6	30.4	58.2

Experiment 1-b

	Turbidity (NTU)				
Strata	0	60	20	10	0
1 to 3	78.6	33.6	36.3	72.2	74.5
4 to 5	21.4	66.4	63.7	27.8	25.5

Experiment 2-a

	Turbidity (NTU)				
Strata	0	60	20	10	0
1 to 3	96.2	49.5	70.9	89.0	89.2
4 to 5	3.8	50.5	29.1	11.0	10.8

Experiment 2-b

	Turbidity (NTU)				
Strata	0	60	20	10	0
1 to 3	89.2	43.8	80.6	88.0	87.0
4 to 5	10.8	56.2	19.4	12.0	13.0

strata was probably difficult. Consequently, fish moved toward the lower strata, allowing them to orient and use the gravel as reference. Movement toward the sides of the channel was also noted. Turbidity levels of 20 NTU and 10 NTU resulted in an increase in visibility from 5 cm to 10 cm and 15 cm to 25 cm, respectively, and a corresponding increase in the frequency of fish in the water column occurred. The increased visibility may have allowed the fish to use visual cues as reference points from higher positions in the water column and, hence, fish moved back up into the higher strata.

In instances where significant differences in vertical distribution were noted within a phase, following a repeated exposure to suspended sediment, consideration of territorial behavior is important. In experiments 1-a and 1-b, 3 of the 4 fish which were territorial in experiment 1-a reestablished their same territories prior to the repeated exposure. In experiment 2, however, territories established during the posttreatment phase were not established by the same fish, nor in the same positions, as in the pretreatment phase. Consequently, the spatial distribution of the fish at the commencement of experiment 2-b differed from that existing at the commencement of experiment 2-a.

The implication of such a shift in vertical position at higher turbidities are numerous. Fish, closely associated with the stream bottom during a sediment pulse, will be subjected to the effects of bedload movement. The often dramatic shifts in the morphometry of stream channels may cause physical damage to the fish. With reference to coho, primarily drift feeders (Hartman 1965), close association with the stream bottom suggests one mechanism by which feeding ability may be decreased. The close association of the fish with the bottom, placing the fish farther away from their food resources, combined with the interference of suspended sediment with vision (to be discussed in a later section) may limit the acquisition of food by coho salmon in turbid water.

Territorial Behavior

The total number of territorial fish at the end of each phase of experiments 1 and 2 is shown in Figure 3. In all cases, a dominant fish established its territory slightly downstream of the middle of the observational arm. The remaining fish were downstream of the dominant fish's position. A minimum of 3 fish had established territories by the end of each pretreatment phase, the remaining nonterritorial fish being mostly positional. Any short excursions by the latter usually resulted in aggressive responses from territorial fish.

Within 15 minutes of the addition of a sediment pulse, territoriality ceased. The fish became very active (Fig. 4), swimming up and down the length of the observational arm. The full length of the arm was utilized to a much greater extent than in the presence of territorial fish (Table 2), as fish were no longer confined downstream of the dominant and other territorial fish.

Further experimental evidence suggesting the absence of territorial behavior is reflected in a study of the behavioral repertoire of the fish. Unfortunately, accurate quantification of behavior at high turbidity levels was difficult and, consequently, the data do not always show significant differences in cases where differences were obvious. Results are discussed where necessary, with reference to the direct observations.

Associated with the presence of territoriality was a high frequency of lateral displaying (Fig. 5). Threat displays and nips were also observed at high frequencies (Figs. 6 and 7, respectively) and were mostly associated with the defence of an area. At turbidity levels of 60 NTU, lateral displaying was observed at a reduced frequency (Fig. 5), threats and nips dominating the behavioral repertoire (Figs. 6 and 7, respectively). The latter were, however, elicited randomly, irrespective of position.

In experiments 1-a and 2-a, 1 territory was established at the end of the 20 NTU treatment phase. Associated with the reappearance of territoriality (Fig. 3) was an increase in the frequency of lateral displaying (Fig. 5, experiments 1-a and 2-a). Although an increase in frequency of lateral displaying was also observed in the absence of territorial fish (Fig. 5, experiments 1-b and 2-b), this can be explained by the observance of several fish making sporadic short-term attempts to establish territories. Fish were still considerably more active at 20 NTU, utilizing the full length of the tank in comparison with pretreatment conditions, but activity did decline as turbidity also decreased (Fig. 4).

At least 1 territory was established within 4 hours of the clearance of the pulse in all 4 cases. The frequency of lateral displaying increased in accordance with the presence of territorial fish (Fig. 5). Threat displays and nips were again associated with the defense of an area.

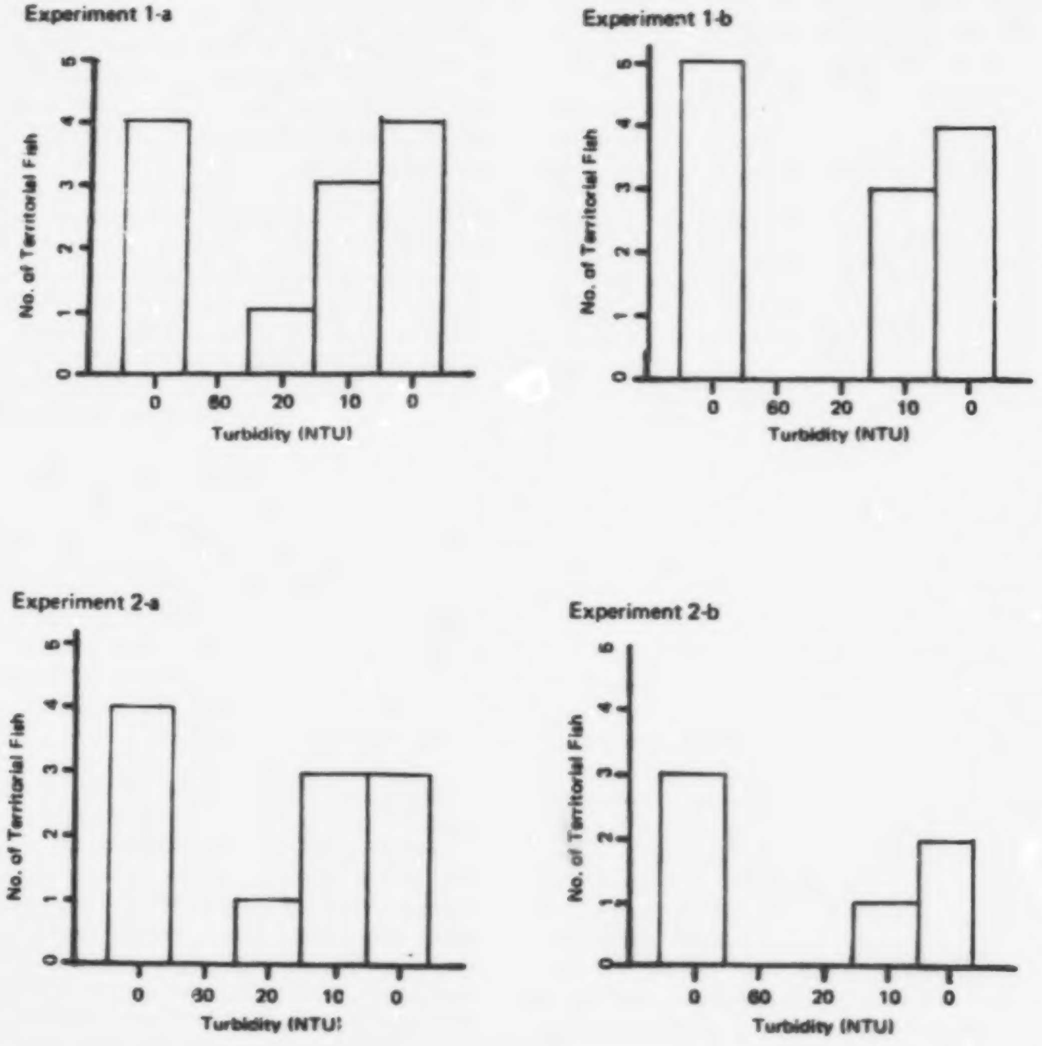


Fig. 3. Frequency of territorial fish at the end of each experiment phase.

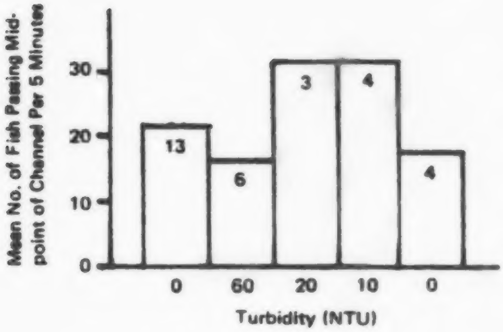


Fig. 4. Activity level of fish in response to suspended sediment concentration. Number of trials shown in bars.

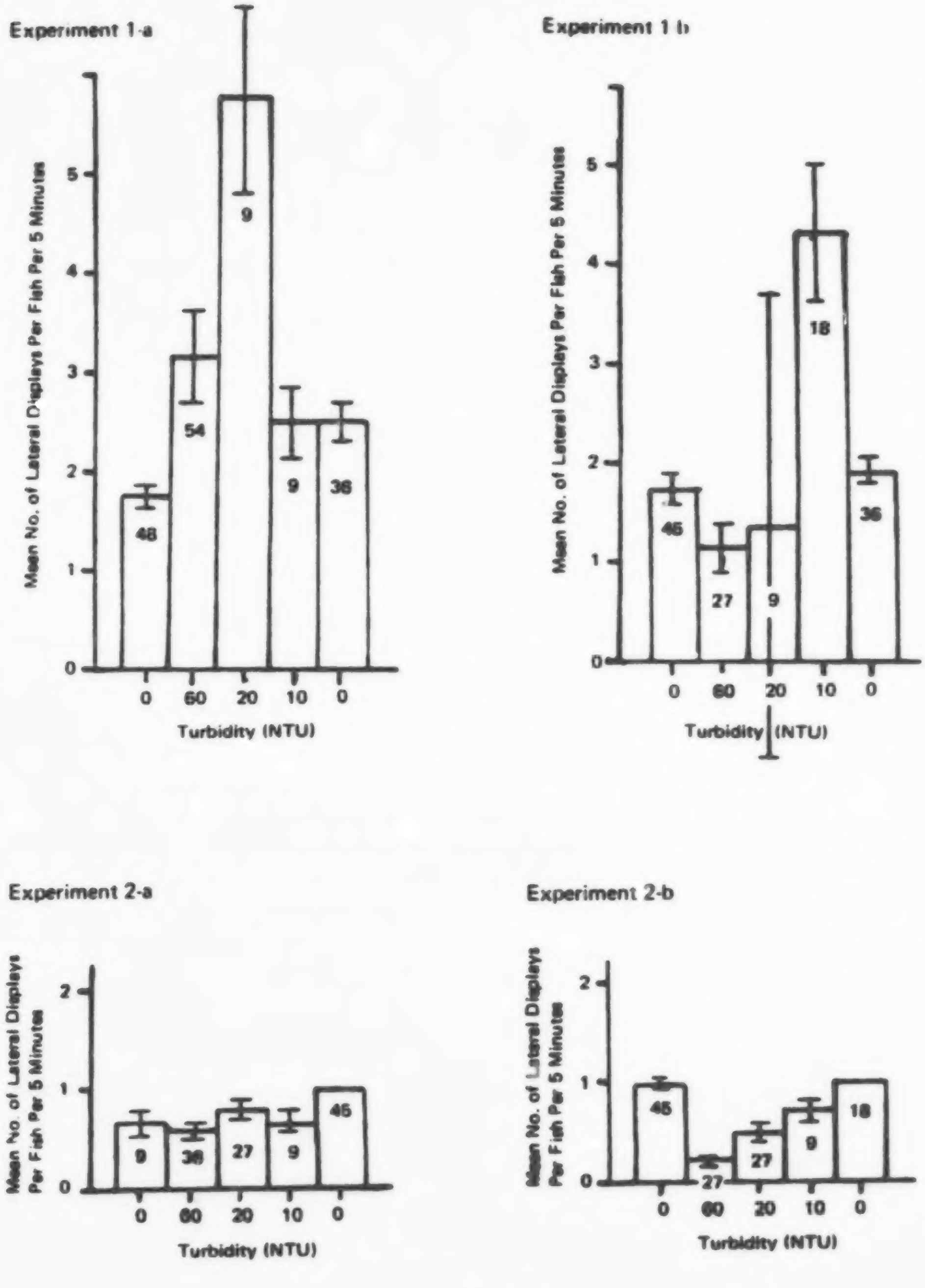


Fig. 5. Frequency of lateral displaying in response to suspended sediment concentration. Standard error and number of trials shown.

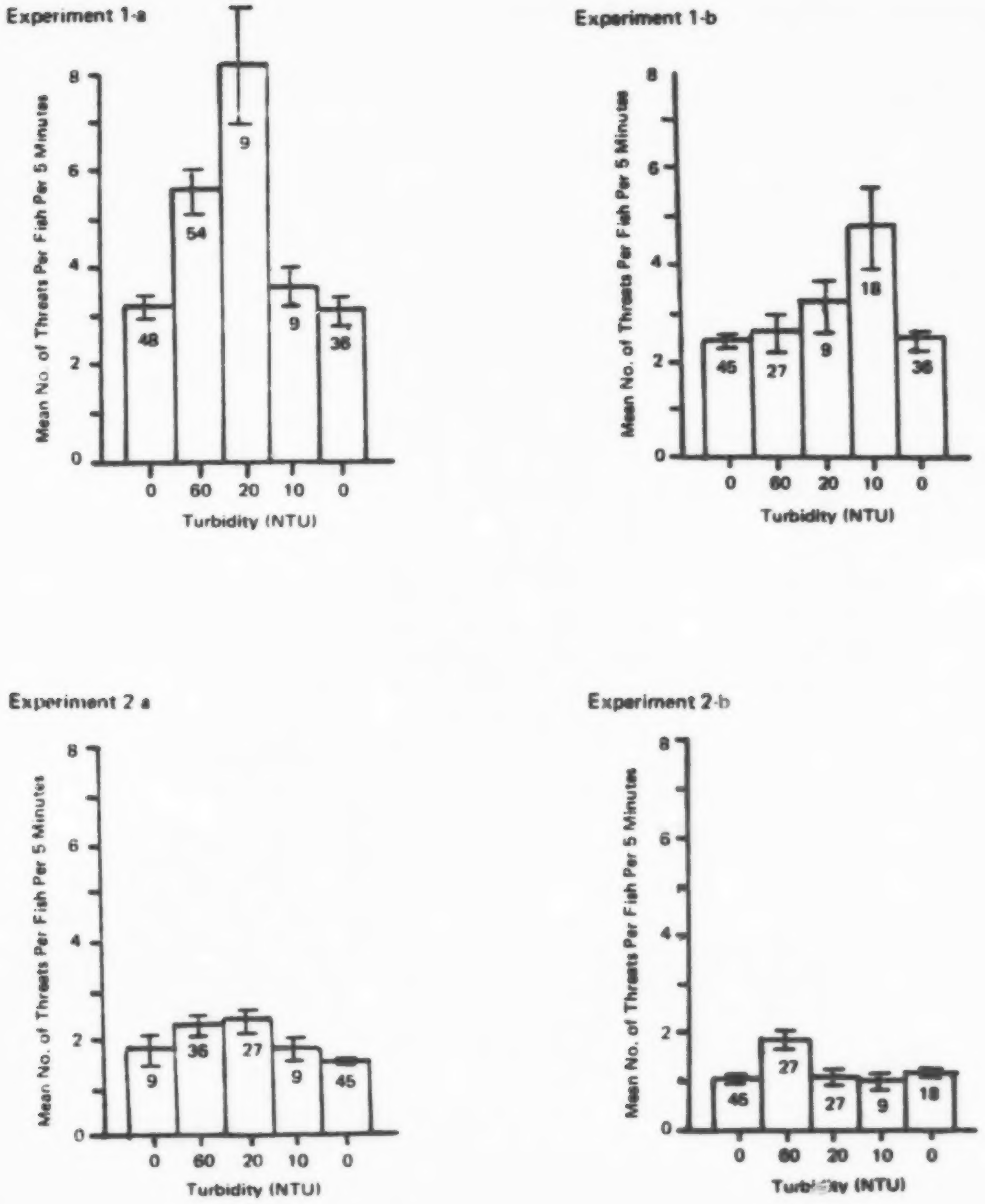


Fig. 6. Frequency of threats in response to suspended sediment concentration. Standard error and number of trials shown.

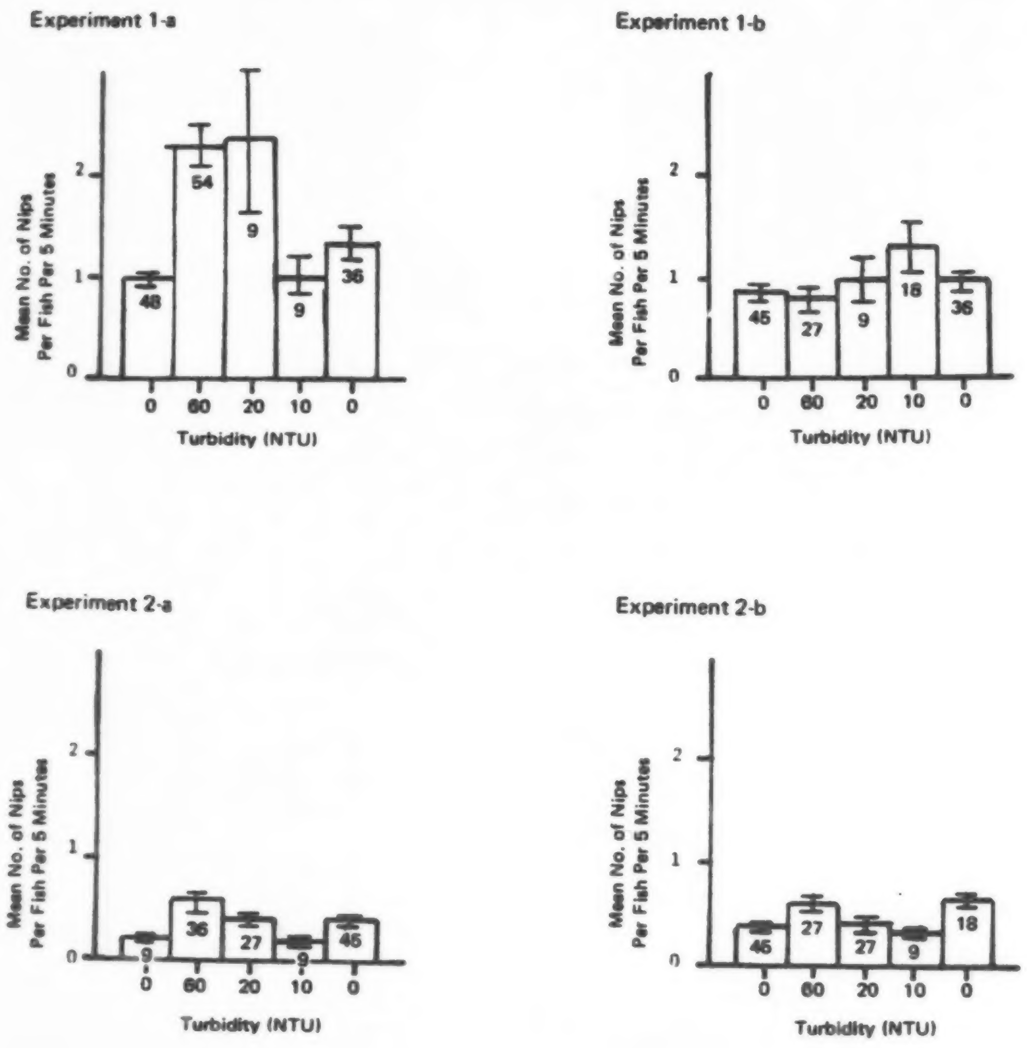


Fig. 7. Frequency of nipping in response to suspended sediment concentration. Standard error and number of trials shown.

Table 2. % distribution of fish along the length of the observational channel in response to a short-term pulse of suspended sediment.

Experiment 1-a

Phase	Turb.	A	B	C	D	E	F	G	H	I	No. of Obs.
Pretreatment	0	0.8	0.0	0.3	0.6	8.2	5.9	17.9	19.8	46.5	340
Treatment	60	2.7	6.3	5.4	9.5	10.4	8.2	20.4	13.2	23.9	222
Treatment	20	0.0	0.0	0.0	14.0	12.3	15.8	33.3	3.6	21.0	57
Treatment	10	0.0	1.3	0.0	13.9	12.7	24.1	25.1	2.6	20.3	79
Posttreatment	0	5.5	0.0	0.0	3.0	7.5	12.2	23.8	16.0	32.0	400

Experiment 1-b

Phase	Turb.	A	B	C	D	E	F	G	H	I	No. of Obs.
Pretreatment	0	0.0	0.0	0.2	2.8	6.0	6.4	16.2	18.2	50.2	500
Treatment	60	1.7	14.1	6.1	11.4	12.3	5.2	11.4	5.2	32.6	113
Treatment	20	0.0	0.0	14.5	1.8	9.1	14.5	20.0	3.7	36.4	55
Treatment	10	0.0	6.2	5.1	2.1	5.2	8.2	25.8	26.8	20.6	97
Posttreatment	0	0.5	0.2	0.0	0.8	7.8	7.6	20.9	21.5	40.7	396

Experiment 2-a

Phase	Turb.	A	B	C	D	E	F	G	H	I	No. of Obs.
Pretreatment	0	0.2	3.0	5.0	6.6	7.8	8.8	24.2	24.8	19.6	500
Treatment	60	4.9	6.0	6.7	4.9	8.4	6.3	12.6	12.6	37.5	285
Treatment	20	0.4	2.6	5.0	4.4	6.6	3.5	13.2	15.0	44.9	227
Treatment	10	0.0	1.0	3.0	0.0	5.0	3.0	23.0	44.0	21.0	100
Posttreatment	0	0.0	0.2	1.0	3.3	2.5	4.3	27.1	35.7	25.9	500

Experiment 2-b

Phase	Turb.	A	B	C	D	E	F	G	H	I	No. of Obs.
Pretreatment	0	0.0	0.2	1.0	3.3	2.5	4.3	27.1	35.7	25.9	500
Treatment	60	3.7	5.9	3.7	5.4	4.8	5.9	12.8	6.4	51.5	187
Treatment	20	0.0	0.0	0.0	0.0	0.0	0.0	17.3	32.7	50.0	98
Treatment	10	0.0	1.0	0.0	0.0	0.0	1.0	13.0	42.0	43.0	100
Posttreatment	0	0.0	0.0	1.5	1.0	4.5	3.0	12.0	33.5	44.5	200

Suspended sediment had a marked effect on the social behavior of juvenile coho. Fish previously territorial at pretreatment conditions became non-territorial following the addition of a sediment pulse. Territoriality was not observed again until turbidity declined to 20 NTU. Visual contact plays an important role in territorial behavior and is supported by the fact that lateral displays (visual displays) are more frequent in the presence of territoriality. The form of use of threats and nips further support the contention that vision is important. In turbid water, threat displays and nips were mostly directed at fish as they suddenly appeared within the visual range of a fish, irrespective of the elicitor's position. In clear water, these behaviors were mostly elicited by territorial fish in response to an intruder.

Thus, suspended sediment not only disrupts the normal social behavior of juvenile coho but also alters the nature of aggressive interactions from exploitative aggression exhibited in clear water to interference aggression exhibited in turbid water (10 NTU to 60 NTU). The ability of suspended sediment to eliminate or depress territoriality can itself produce a number of secondary effects. A decrease in growth and/or survival of juvenile coho rearing in streams affected by frequent short-term pulses of suspended sediment may result. The establishment of a territory by stream fishes has been suggested to be a behavior evolved to assure adequate food supplies (Kalleberg 1958). Territoriality has also been shown to correlate with greater individual survival potential (Allee 1938; Collias 1944). Consequently, the possibility exists that fish exposed to frequent yet short-term pulses of suspended sediment may exhibit lower growth and/or survival rates in streams subjected to suspended sediment.

Although it is sometimes difficult to infer responses under field conditions from laboratory studies, the observed increase in activity, allowed in part by the absence of territoriality at higher turbidities, suggests that fish may actively migrate in the event of a suspended sediment pulse if given the choice. Sigler (1980) reports an increase in downstream movement of coho fry reared in turbid water, in comparison with the movement of fry reared in clear water. Fish may be placed in unfavorable environments where

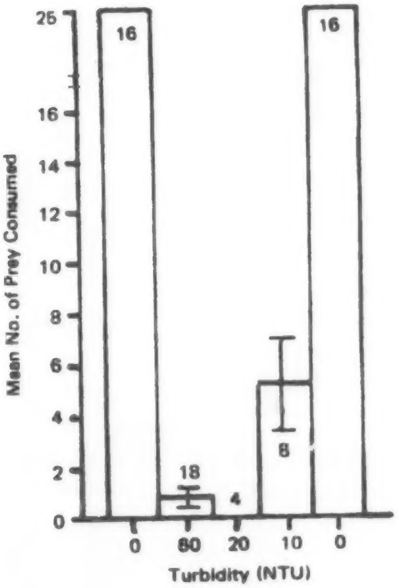


Fig. 8. Feeding ability of coho in response to suspended sediment concentration. Standard error and number of trials shown.

food or habitat availability may not be adequate, thereby decreasing the quality and/or production of fish in streams affected by suspended sediment.

Feeding Behavior and Vision

Throughout the feeding experiments, one fish positioned slightly upstream of the others made most of the feeding movements. In Figure 8, the mean number of surface prey items consumed is shown for each turbidity level. At 0 NTU, 100% of the prey items offered were successfully consumed. At 60 NTU, only 35% of the introduced prey items were ingested. In 4 of the trials, only fish which happened to be near the water surface consumed the prey. As turbidity declined to 10 NTU, 21% of the prey items were consumed and consumption increased to 100% as turbidity decreased to 0 NTU.

At a turbidity level of 10 NTU, fish were noted to frequently misstrike at prey items (Table 3), suggesting that the sediment interfered with vision. Interference of suspended sediment with the visual ability of fish was further inferred by the frequent collision of some fish with a small protuberance on the inside of the channel in turbid water (Fig. 9). A decline in frequency of collisions noted during a phase (60, 20, and 10 NTU) was attributable, in part, to a learning experience by the fish. Initially, a fish swimming along the channel wall would collide head-on with the projection, but often within 45 minutes, the same fish would be observed to actively avoid the projection. It is questionable as to whether or not the decrease in bumping frequency following repeated exposure was attributable to prior experience.

Observations on feeding were also made during the behavioral observations. The response time of the fish to the pulse of food added at time = 15 minutes is shown in Table 4. A significant delay in the response of the fish to the food was noted at the higher turbidities (60 NTU to 20 NTU). Also noted was the "disinterest" of some fish to feed in turbid water. In experiment 2-b, 1 fish which also happened to be the smallest fish was not observed to partake in feeding. This fish died 6 days after the experiment terminated.

Thus, suspended sediment had a marked effect on the visual ability of juvenile coho. Fish frequently collided with the protuberance on the side wall of the channel and were observed to be startled by the sudden appearance of other fish. Reduced capture rates of prey items, misstrikes at prey items, and significant increases in response time to the pulse of food added during behavioral observations all imply that vision was impaired by the presence of suspended sediment.

As coho are visual feeders, feeding primarily on drift (Hartman 1965), the acquisition of food resources in turbid water may be significantly reduced because of the combined effects of turbidity on behavior and vision. The behavioral response of fish to move closer to the bottom substrate in turbid water moves fish farther from their food resources. The scattering and absorption of light by suspended particles decreases light intensity, reducing the ability of fish to detect potential prey items.

The result of a decreased feeding ability of fish in turbid water may lead to depressed growth rates. An increase in susceptability to disease and a decrease in ability to withstand unfavorable abiotic conditions may lead to a consequent decrease in the production and quality of juvenile salmonids.

Coughing

The frequency of coughing at each treatment phase is shown in Figure 10. Coughing rates increased significantly in experiments 1-a and 1-b, but no significant differences could be detected in either experiment 2-a or 2-b ($p = 0.05$). As turbidity declined to 10 NTU, coughing declined or remained at an elevated pretreatment level. Except in experiment 2-b, coughing appeared to decrease in posttreatment conditions. Quantification in turbid water, however, was difficult.

Although a thorough investigation into the physiological effects of suspended sediment on fish was not undertaken in this study, there was some indication that exposure to even short-term pulses of suspended sediment does produce significant physiological responses in fish. The gills of fish are delicate structures and are therefore easily damaged by the abrasive action of the silt particles. In the initial stages, as silt begins to accumulate in between the gill filaments, fish attempt to rid the gills of the silt by excessive opening and closing of the gill opercula. As irritation progresses, an increase in the secretion of mucus occurs, producing a heavy covering of mucus over the gill surface. Such alterations to the histological structure of the gill only serves to seriously impede the circulation of water over the gills and interfere with the respiratory functioning of the gills.

Table 3. Frequency of feeding misstrikes in response to suspended sediment.

Phase	No. of Trials	Turbidity	No. of Misstrikes at Sighted Prey Items Per Trial
Pretreatment	16	0	0
Treatment	8	60	0
	4	20	0
	8	10	2.7
Posttreatment	16	0	0

Table 4. Response time of coho to the addition of food added during the behavioral observations. (Standard error is in brackets.)

Experiment	0 NTU	60 NTU	20 NTU	10 NTU	0 NTU
1-a	1.30 (0.45)	2.30 (0.57)	2.00 (0.20)	1.50 (0.00)	1.00 (0.00)
1-b	1.10 (0.23)	2.80 (0.76)	2.50 (0.00)	2.20 (0.72)	1.10 (0.22)
2-a	1.00 (0.00)	2.70 (0.30)	2.60 (0.30)	2.00 (0.00)	1.00 (0.35)
2-b	1.00 (0.00)	2.50 (0.71)	3.00 (0.00)	2.50 (0.00)	1.00 (0.00)

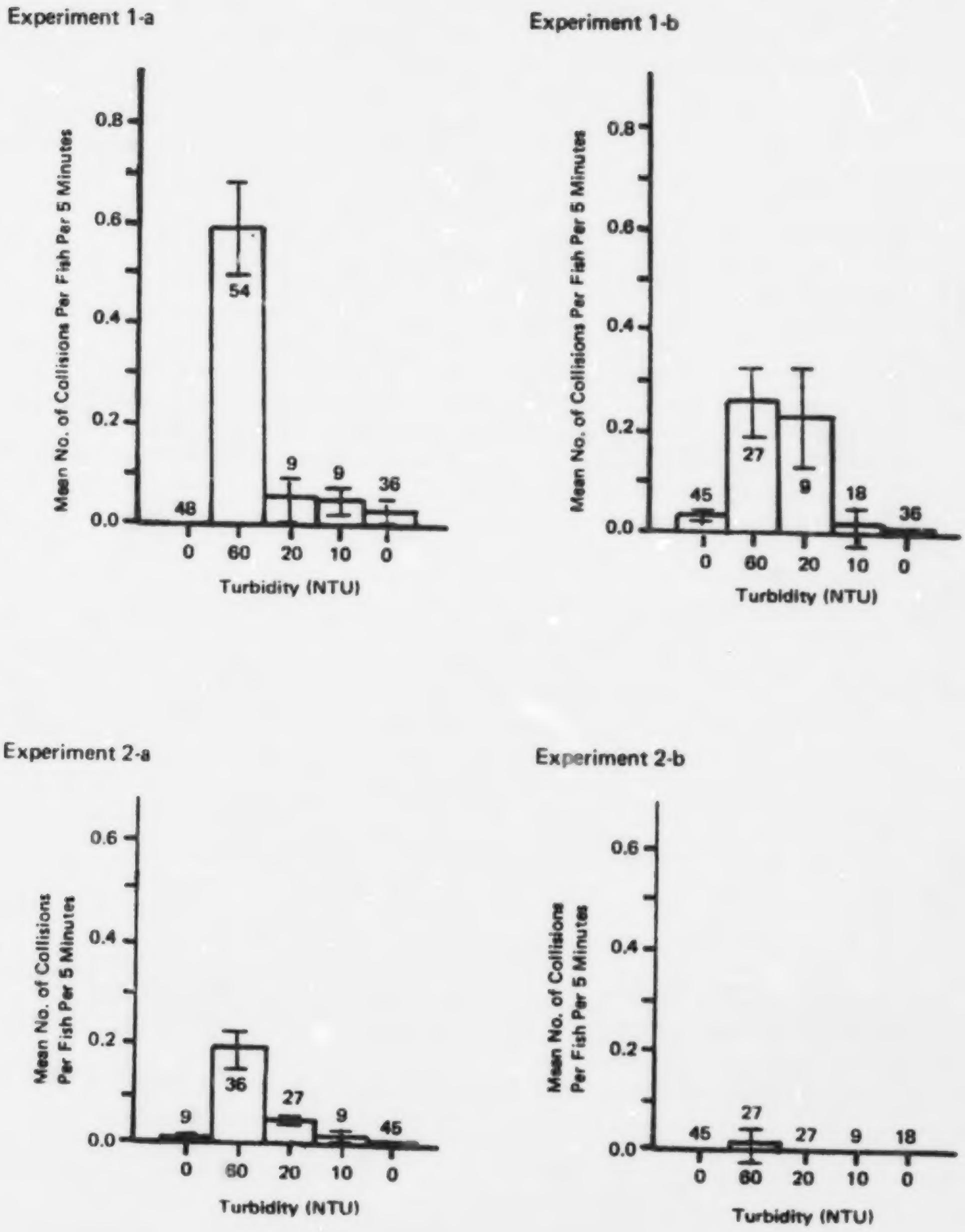
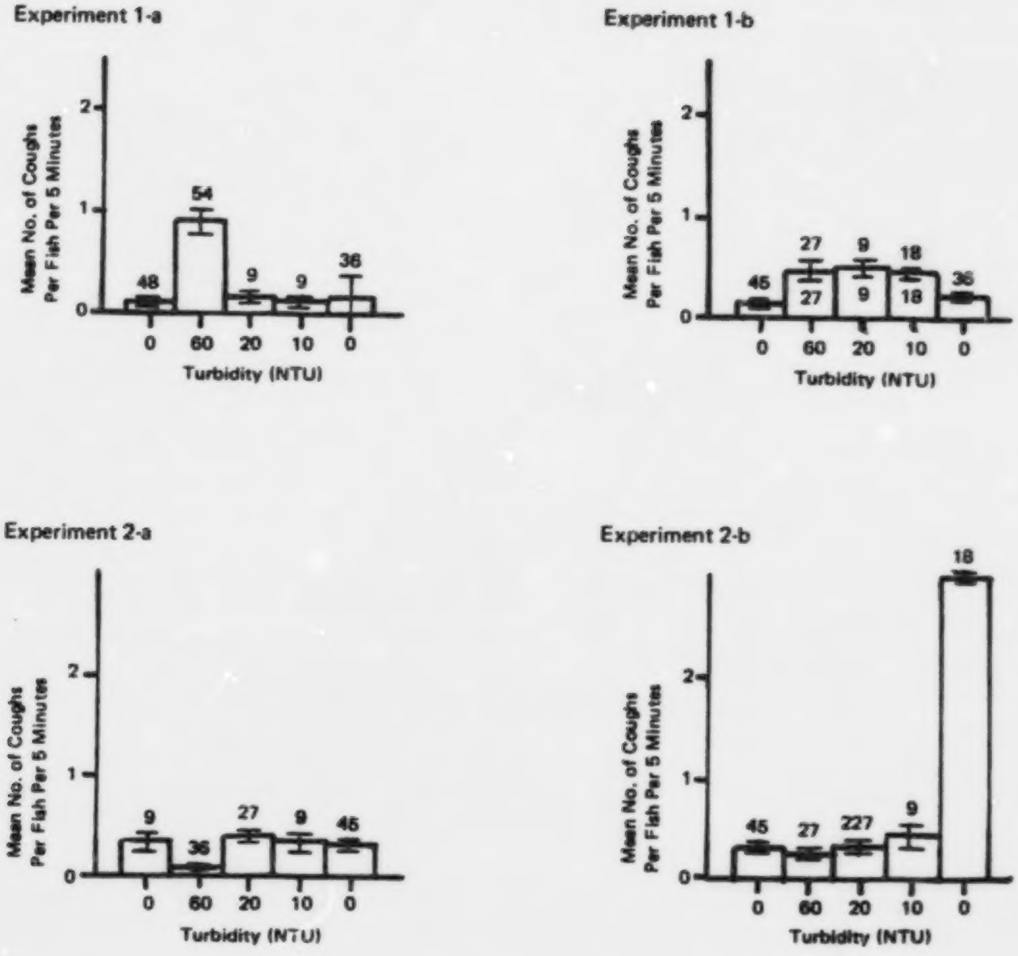


Fig. 9. Frequency of collisions in response to suspended sediment concentration. Standard error and number of trials shown.



Experiment 1-a

Experiment 1-b

Experiment 2-a

Experiment 2-b

Fig. 10. Frequency of coughing in juvenile coho in response to suspended sediment concentration. Standard error and number of trials shown.

Short-term exposure to suspended sediment does therefore have a marked effect on the physiology of fish. Irritation to the gills occurs, thereby rendering fish suceptible to disease, as lesions to the gill surface may result from the abrasive actions of sediment. Subsequently, metabolic stresses may be inflicted because of a decrease in the respiratory efficiency of the gills.

SUMMARY

Past studies have shown that chronic exposure to suspended sediment can produce a number of adverse effects on fish—both directly and indirectly. This study strongly indicates that even exposure to short-term pulses of suspended sediment induce unfavorable alterations in the behavior and physiology of juvenile coho salmon:

1. Social organization of coho was disrupted.
2. Spatial position of coho was altered.
3. Feeding ability and visual ability of coho was decreased.
4. Physiological stresses were experienced.

CONCLUSION

Frequent exposure to short-term pulses of suspended sediment at levels of only 60 NTU produces alterations in the behavior of juvenile coho salmon. In many streams of logged watersheds, turbidity levels often reach much higher values, implying that the deleterious effects of short-term exposure to suspended sediment may in fact be much more pronounced than as evidenced in this study.

Suspended sediment may therefore potentiate decreases in individual survival and/or decreases in quality of fry. Subsequently, a decrease in the diversity of a species and, hence, the presence of a valuable fisheries resource in coastal streams are threatened.

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THE IMPACT OF LOGGING ON PERIPHYTON BIOMASS AND SPECIES COMPOSITION IN CARNATION CREEK: A COASTAL RAIN FOREST STREAM ON VANCOUVER ISLAND, BRITISH COLUMBIA

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ABSTRACT

Periphyton biomass, species composition, and accumulation rates on plexiglass substrates were determined from 1974 to 1979 in Carnation Creek. During the first three years of the study, the watershed was unlogged. Clear-cut logging in the remainder of the study resulted in increases in light intensity of over 100% at some sites, slight increases in stream temperature (2° to 3°C in summer), and increases in some dissolved nutrient concentrations. Diatoms were the most common class of algae throughout the study, and *Achnanthes minutissima* and *Synedra rumpens* were the most common diatoms. Filamentous chlorophytes (*Draparnaldia* sp., *Mougeotia* sp., *Spirogyra* sp., and *Zygnema* sp.) occurred sporadically throughout the study but were more common after logging.

Highest recorded periphyton biomass and accumulation rates occurred after logging, although post-logging values were not consistently higher than those recorded prior to logging.

INTRODUCTION

Although considerable work has been done on the Pacific Coast of Canada and the United States on effects of logging on abiotic factors in streams (hydrology, temperature, suspended sediment, etc.), little work is available on effects of clear-cut logging practices on stream periphyton. Previous studies (Hansmann 1969; Lyford and Gregory 1975; Murphy and Hall 1981) have taken place primarily in western Oregon, where edaphic, climatic, and attendant physical and chemical factors differ widely from those on the west coast of Vancouver Island. These differences (which will be discussed later in the text) make extrapolation of findings from the Pacific Northwest of the United States to the Pacific Coast of Canada difficult. However, certain factors (runoff patterns, annual rainfall, and forest associations) in Carnation Creek are representative of streams on much of the British Columbia coast (Narver 1974), and it is felt that results from the Carnation Creek Study may be cautiously extrapolated to many B.C. coastal drainage basins.

This investigation of the attached algal component of a coastal rain forest stream ecosystem was part of the large, multidisciplinary Carnation Creek Experimental Watershed Project. The larger project commenced in 1970 and is expected to continue until 1985, while sample collection for this study took place over a six-year period (1974 to 1979).

The objectives of the study were to quantify attached algal biomass and species composition before and after logging of selected portions of the stream drainage basin and to determine effects of changing abiotic and biotic factors on attached algal growth in the streambed. Findings from this study will, in future, be integrated with those from all components of this multidisciplinary project in an effort to improve guidelines for coastal logging practices that will provide maximum benefits with minimum damage to the stream environment and the salmonid resource.

DESCRIPTION OF STUDY AREA

Carnation Creek (lat. 48°55', long. 125°00') flows into Barkley Sound on the west coast of Vancouver Island (Fig. 1). Much of the 10 km^2 watershed, which contains no lakes, consists of steep slopes rising to a maximum of 700 m in elevation. In winter, snow occasionally accumulates in the higher areas of the watershed, but the duration of snowpack is usually brief. Annual rainfall ranges from 2.6 m to 3.6 m and streamflow is highly variable, ranging from $< 0.02\ m^3.s^{-1}$ in late summer to $> 36\ m^3.s^{-1}$ in some winter freshets. Prior to logging, the drainage basin was heavily forested with western hemlock (*Tsuga heterophylla*), amabilis fir (*Abies amabilis*), and western red cedar (*Thuja plicata*). Logging in select portions of the drainage basin commenced in the winter of 1975-1976 and continued until 1980 (Fig. 1). Logging operations generally were carried out only from October to March of each year. At the conclusion of this study in 1980, approximately 34% of the basin was logged (Anon. 1979).

METHODS

Periphyton samplers were placed in a variety of sites within predefined study areas in the creek. Most samplers were located in the lower 2.4 km of the creek, where it passes through a floodplain with an average slope of < 2% (Fig. 1).

The samplers consisted of plexiglass plates with a 400 cm^2 sampling area roughened by fine sandpaper. The plates (sampling area uppermost) were bolted to concrete blocks approximately 50 kg in weight which were partially buried in the stream bottom. At approximately one-month intervals, accumulated growth in the sampling area of the plate was removed and placed in a glass jar; algae present on other areas of the plate were removed and discarded.

Within two hours of sample collection, the contents of each jar were split into three portions using a plankton splitter. One portion was filtered onto a Whatman glass fibre filter (GF/C), a few drops of saturated $MgCO_3$ solution were added, and the filter frozen. Filters were later macerated in 90% acetone and the extracted chlorophyll was measured using a Cary (Model 15) recording spectrophotometer, except for the last two years of the study when a Turner (Model 111) fluorometer was used. Strickland and Parsons' (1972) equation was used to calculate chlorophyll concentrations.

Another portion of sample was filtered onto a Whatman GF/C filter which had been ashed and weighed. This filter was frozen and later dried at 100°C to constant weight, weighed, ashed at 460°C for 4 hours, and weighed again. Results are expressed as ash-free dry weight (AFDW).

The third portion was placed in a glass jar and preserved with Lugol's acetate solution. A portion of this sample was enumerated using a Wild M40 inverted microscope, and algae other than diatoms were identified to the genus level. Cell dimensions and volumes were also calculated and recorded.

Permanent quantitative slides of diatoms were made using methods described by Stockner and Armstrong (1971) and diatoms were counted, identified, and measured and volumes and relative abundance were calculated.

On several occasions during each year of the study, qualitative samples of periphyton were collected from natural substrate (rocks) near each stream sampler. Algal species composition was determined from these samples and compared to samples from the nearest stream sampler. More detailed accounts of the biological methods used in this study may be found in Stockner and Shortreed (1976).

Much of the physical and chemical stream data used in this report were collected by other investigators. These data are presented in detail in Scrivener (1975) and Scrivener (1982).

Light data ($g.cal.cm^{-2}.d^{-1}$) were taken continuously during the study using a Belfort recording pyrheliometer that was placed on a clear-cut logged hill adjacent to the estuary of Carnation Creek. For each year during the growing season, another calibrated pyrheliometer was placed beside each periphyton sampler for a two-week period. Percentage of total available light reaching the samplers was calculated from these data.

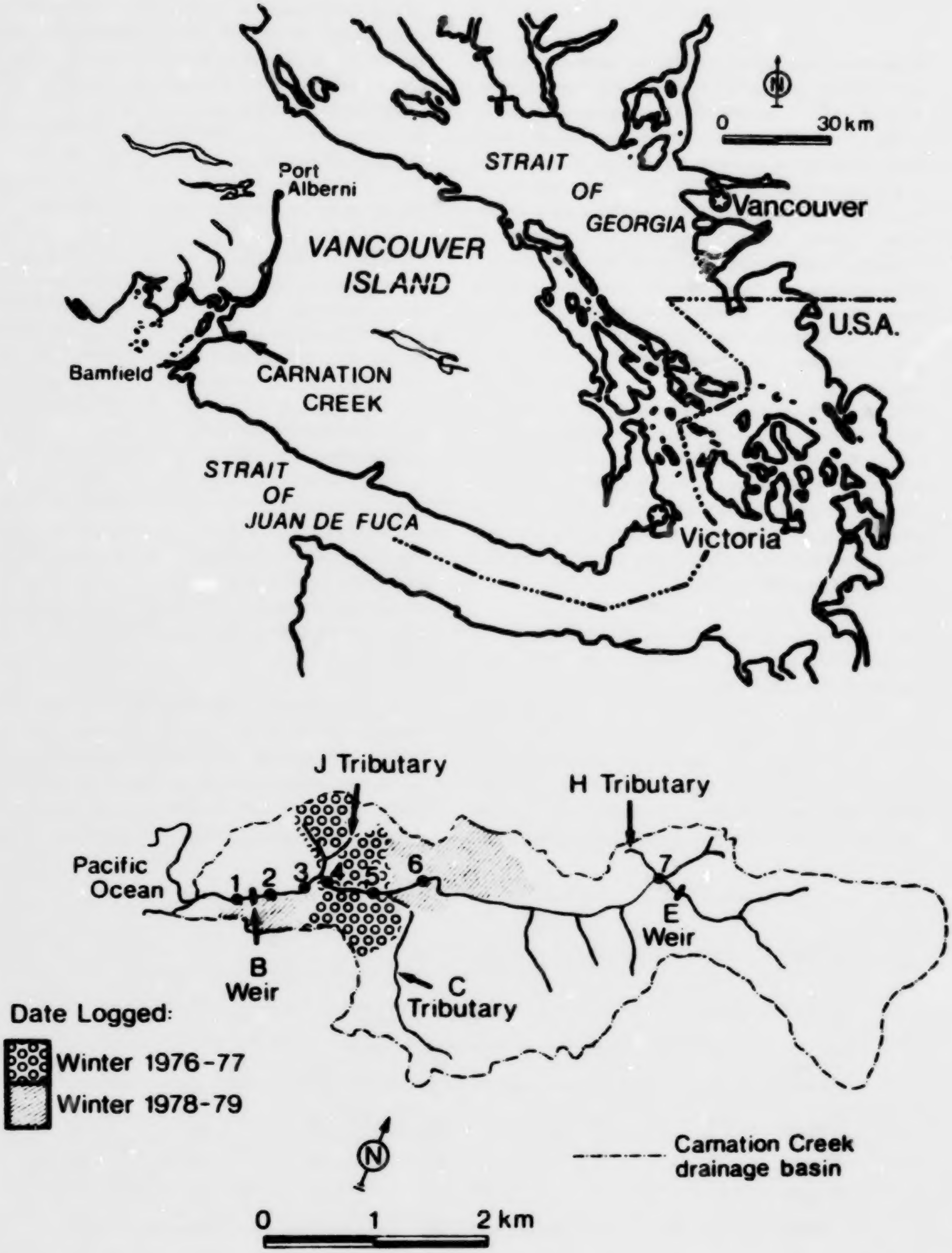
0
30 km
Port Alberni
STRAIT OF GEORGIA
Vancouver
VANCOUVER ISLAND
U.S.A.
Bamfield
CARNATION CREEK
STRAIT OF JUAN DE FUCA
Victoria
J Tributary
H Tributary
Pacific Ocean
1
2
3
4
5
6
7
B Weir
E Weir
C Tributary
Date Logged:
Winter 1976-77
Winter 1978-79
Carnation Creek drainage basin
0
1
2 km

Fig. 1. Map of study area and major logging activities.

RESULTS

Streamflow was highly variable in Carnation Creek, both before and after logging, and ranged from < 0.03 $m^3.s^{-1}$ during some summer periods to > 28 $m^3.s^{-1}$ in some winter freshets. On occasion, flow varied by as much as two orders of magnitude in a single 24-hour period (Fig. 2). During most years, flows were low and stable for approximately a five-month period between May-June and September-October. It was during this period that the greatest accumulations of algal biomass occurred. Highest mean daily water temperatures in summer were 11° to 12°C prior to logging and 14° to 15°C after. Before removal of the forest canopy by logging, light reaching the six sampling sites ranged from 24% to 47% of the total available (Table 1). After logging, the percentage of available light reaching the samplers ranged from 46% to 97%. Site 2 was least affected by canopy removal because of its location in a narrow, steep-sided area of the valley bottom. At site 5, effects of logging on light intensity were greatest. The percentage of available light reaching this site increased from 40% to 97%.

Dissolved nutrient concentrations (nitrogen and phosphorus) were variable throughout the study, and changes as a result of logging did not take place until October 1977. In September 1977, a 61 ha area which had been logged the previous winter was burned to remove the slash, and after this date, nutrient concentrations during freshets tended to be higher than before logging (Scrivener 1982). However, during most low-flow periods, dissolved phosphorus concentrations were similar to those prior to logging and burning. Nitrate concentrations downstream of the burned areas remained higher than before logging, even during the low-flow periods. Nitrate ranged from 2 to 140 $\mu g\ N.L^{-1}$ prior to the fall of 1977 and from 16 to 230 thereafter. Dissolved phosphorus concentrations were more variable after logging (ranging from < 1 to 28 $\mu g.L^{-1}$) than they were before, when they ranged from < 1 to 9 $\mu g.L^{-1}$.

Throughout the study, periphyton biomass was lowest during times of high and variable flow, as frequent scouring of the streambed occurred at these times. Periods of low, stable flow were required before periphyton could accumulate (Fig. 2). These periods of low flow with stable substrate and limited scouring coincided with times of high light intensities and maximum temperatures. The seasonal pattern of lowest biomass levels in winter and highest in summer or early fall occurred at all sampling stations throughout the six-year study period. Biomass (as chlorophyll) ranged from 0 $mg.m^{-2}$ during high-flow periods in winter to > 5 $mg.m^{-2}$ during some low-flow periods in summer or early fall. Only on one occasion was a concentration of > 10 $mg.m^{-2}$ observed. Average growing season chlorophyll values are listed in Table 2.

Algal accumulation rates (ash-free dry weight/days between sampling intervals) ranged from 0 $g.m^{-2}.d^{-1}$ during times of high and variable flow to 0.28 $g.m^{-2}.d^{-1}$ during stable low-flow periods in summer or fall. Highest accumulation rates at most stations occurred in the postlogging portion of the study, although

Table 1. Percent of light reaching the stream samplers.

	Site					
Year	1	2	3	4	5	6
1974	----	47	40	39	40	32
1975	----	----	37	35	44	36
1976	----	----	----	32	41	----
1977	31	24	36	77	95	41
1978	44	24	53	----	97	32
1979	85	46	48	92	97	71

Table 2. Average growing season chlorophyll concentrations in mg.m^{-2}.

Year	Site 1	2	3	4	5	6
1974	-------	2.26	1.60	2.51	1.77	3.66
1975	-------	1.72	0.70	1.64	0.78	0.72
1976	2.82	2.51	1.54	2.97	1.48	3.54
1977	6.70	1.40	0.80	0.45	1.06	1.32
1978	2.25	1.87	2.78	4.44	1.95	2.86
1979	4.98	0.92	1.65	------	0.70	------

Table 3. Average growing season accumulation rates (mg ash-free dry weight. m^{-2}.d^{-1}).

Year	Site 1	2	3	4	5	6
1974	----	74	55	77	20	48
1975	----	26	36	80	13	34
1976	93	51	29	40	22	69
1977	79	31	----	25	19	67
1978	54	25	36	118	55	51
1979	96	38	45	81	74	38

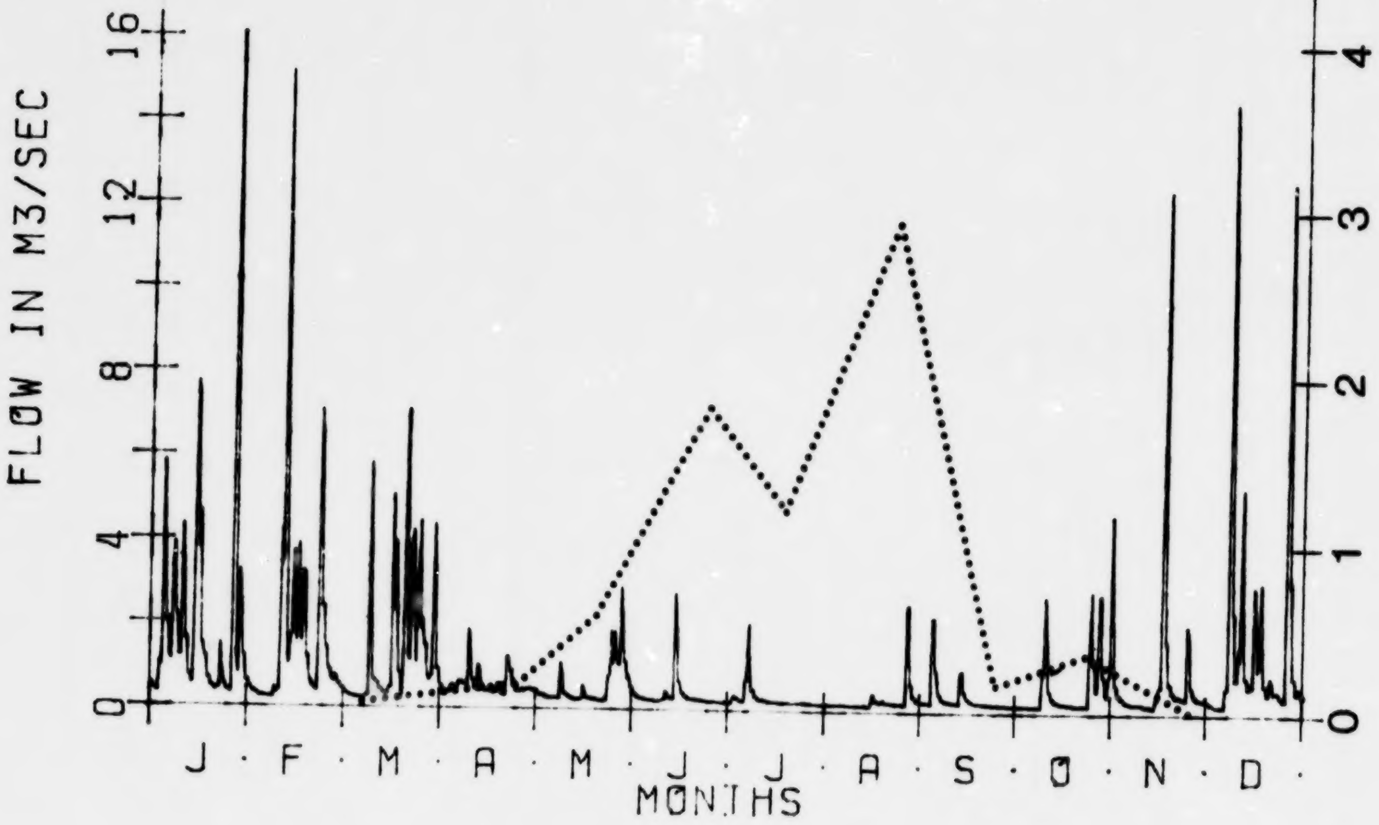

Fig. 2. Annual hydrograph (1976) and algal volume for site 3 during that year.

differences were not apparent at all stations (Table 3, Fig. 3). The marked increases in accumulation rates at site 5 in 1978 and 1979 may be partially due to the changes in current velocity at this site which occurred after large freshets in the fall and winter of 1977 (Horner and Welch 1981). Current velocity during low-flow periods was 50 to 60 cm.s^{-1} prior to the winter of 1977-1978 and 20 to 30 thereafter.

The low average accumulation rates recorded at sites 4 and 5 in 1977 were due to the considerable amount of small and large organic debris present in the stream after logging, which occurred in this area during the previous winter and spring. For much of this year, the streambed was covered by this debris, which remained in the stream until freshets occurred in the fall and winter of 1977.

Common algae during the study were the diatoms *Achnanthes minutissima*, *Synedra rumpens*, *Diatoma hiemale*, *Eunotia pectinalis*, *E. tenella*, *Gomphonema parvulum*, and *Synedra ulna*. Other common algae were the coccoid chlorophyte *Chlorococcum* sp. and the filamentous chlorophytes *Draparnaldia* sp., *Mougeotia* sp., *Spirogyra* sp., and *Zygnema* sp. During periods of high and variable flow (late fall, winter, early spring) and frequent scouring of the substrate, dominant algae were small (< 5 μm in diameter) coccoid chlorophytes, of which *Chlorococcum* sp. was most common. However, during the growing season (spring, summer, fall), diatoms were usually dominant. *A. minutissima* was the most common diatom at all sites in Carnation Creek on almost all sampling dates, comprising $> 60\%$ of total diatom numbers in the majority of instances (Fig. 4). *S. rumpens* also occurred at all sites on almost all dates, but seldom comprised $> 10\%$ of total diatom numbers.

During periods of low, stable flow and high light, filamentous chlorophytes (*Draparnaldia* sp., *Mougeotia* sp., *Spirogyra* sp., and *Zygnema* sp.) occasionally became common. After logging, their relative abundance during these periods increased and they, at times, formed conspicuous algal "mats" which covered portions of the strembed in logged-over sections of the stream.

The sampling technique used in this study (artificial substrates scraped clean at approximately monthly intervals) appeared to underestimate the abundance of filamentous chlorophytes and, consequently, the data do not accurately indicate their actual abundance. However, qualitative observations of the easily visible accumulations of filamentous chlorophytes indicated that their occurrence was both patchy and sporadic and that, after logging, diatoms remained the dominant algal group in Carnation Creek.

Qualitative comparisons of periphyton species composition on both artificial and natural substrates indicated that the composition was very similar. *A. minutissima* was dominant on both substrates and other algae commonly found on plexiglass plates were also common on the streambed. The sole exceptions were the occasions when filamentous chlorophytes became dominant on the natural substrate and were not as abundant on the artificial.

DISCUSSION

Periphyton accumulation rates and the resulting standing crop in Carnation Creek, as in most streams, were influenced by a number of physical, chemical, and biological factors, many of which were altered as a result of logging. Of the physical factors (light, temperature, flow, substrate quality, and availability) least important was temperature, as maximum daily summer temperatures increased by only 2° to 3°C. Phinney and McIntire (1965) found that, given an adequate supply of light and nutrients, periphyton in laboratory streams had a Q_{10} of approximately 2 for the temperature range 6° to 18°C. However, the nutrient supply in Carnation Creek, which will be discussed shortly, was not adequate and likely negated the possible positive effects of increased temperature. Streamflow was not affected by logging, as both peak winter flows and low flows during summer were similar before and after logging. However, flow played an important role in limiting periphyton biomass in the stream. While it had little influence on periphyton biomass during the growing season (when flows were low and stable), it did effectively limit the duration of the growing season. When flows were high and variable, losses through scouring were considerable and periphyton could not accumulate (Fig. 5). During periods of low flow, periphyton accumulation rates varied widely, but during high-flow periods, accumulation rates were uniformly low. Only when flow was low and stable could other environmental factors influence periphyton growth and abundance.

Changes in streambed composition occurred after logging in Carnation Creek. Removal of streamside vegetation in some sections of the stream resulted in

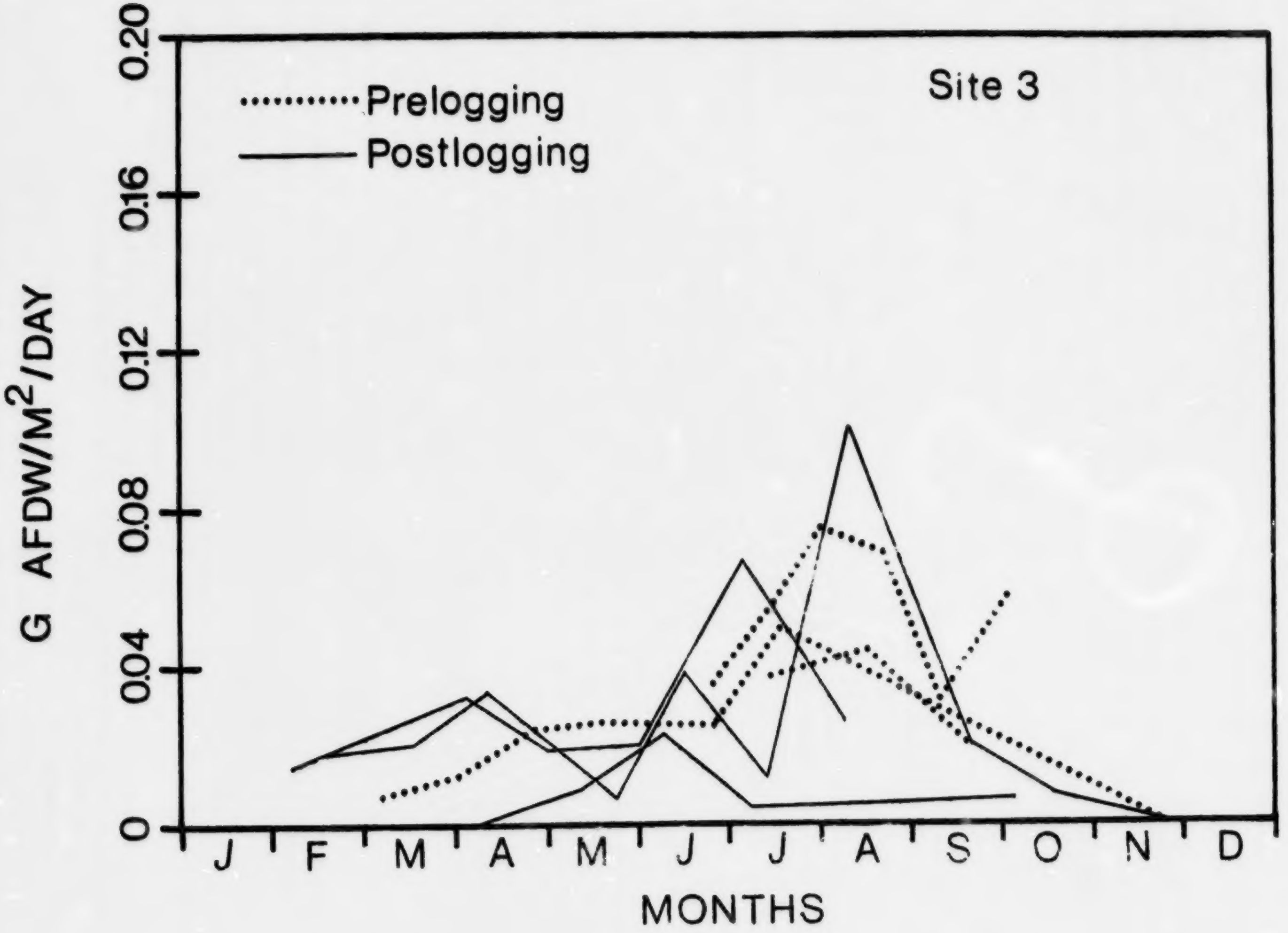

Fig. 3. Algal accumulation rates at site 3 during prelogging (1974 to 1976) and postlogging (1977 to 1979) portions of the study.

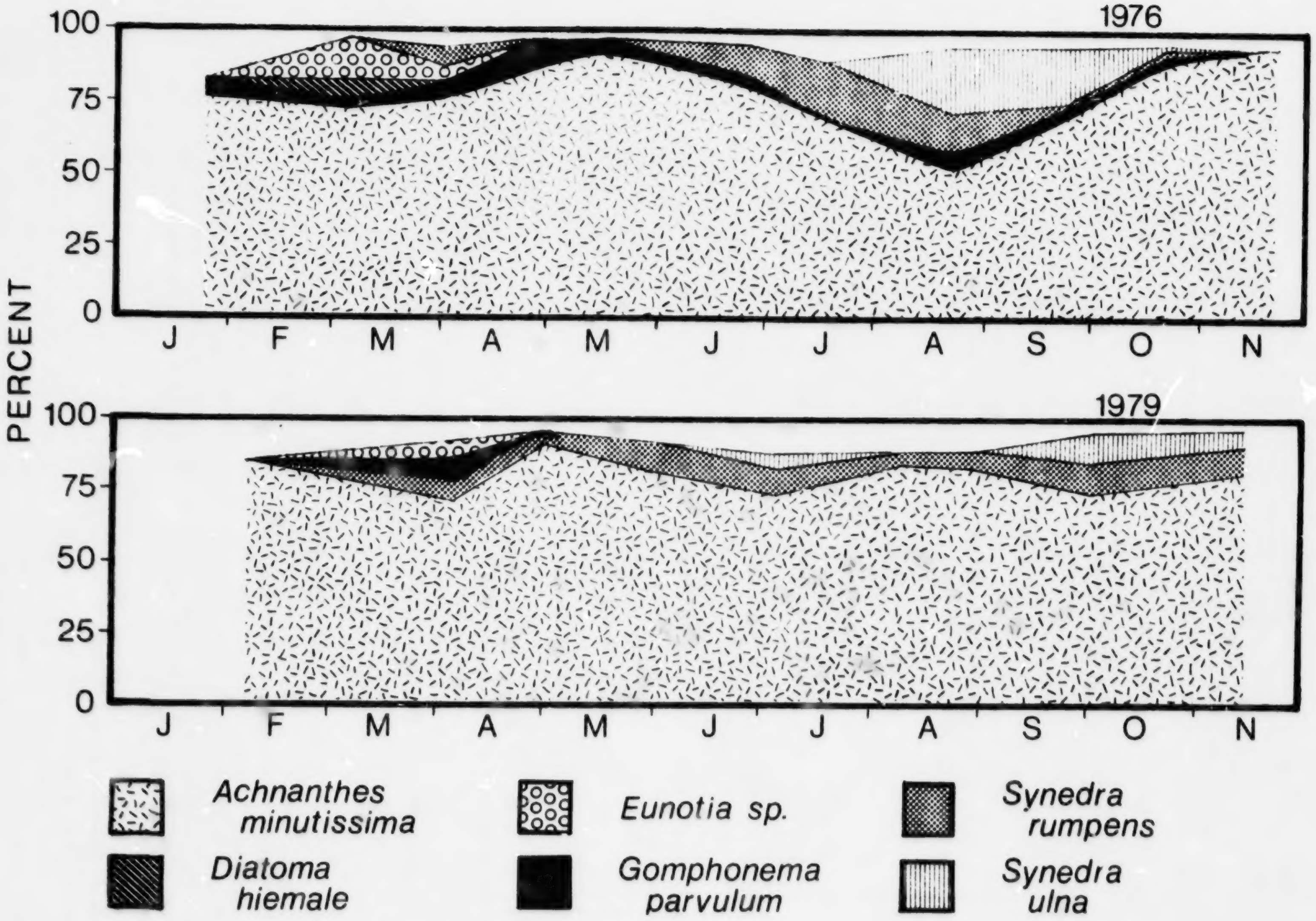

Fig. 4. Relative diatom abundance at site 1 during 1976 and 1979.

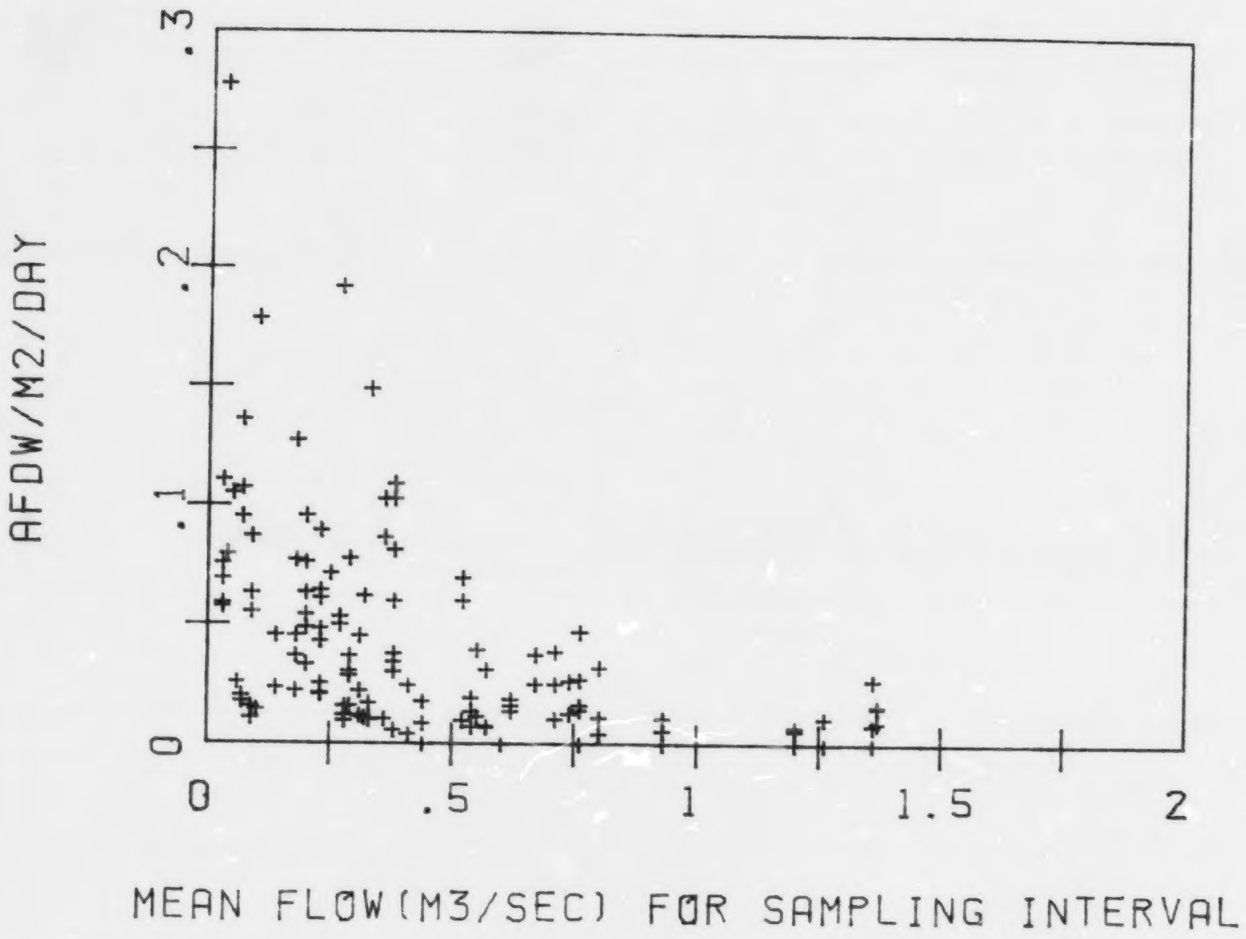

Fig. 5. Algal accumulation rates (AFDW per day) versus flow.

increased erosion of the streambank and consequent higher input of inorganic material, especially silt. Scrivener and Brownlee (1980) reported an increase in the percentage of material < 9.55 mm in diameter in the top layer of gravel. This increase in fine material after logging has been observed in a number of other systems (Adams and Beschta 1980; Hansmann 1969). Owing to its size, this material is relatively unstable and is a poor substrate for periphyton attachment and growth (McConnell and Sigler 1959). While the samplers in this study were not affected by changes in gravel quality (at least during low-flow periods), decreased periphyton abundance in the creek as a result of a decrease in suitable natural substrate may have occurred (but unfortunately was not measured) in some sections of Carnation Creek after logging. Once growth of new vegetation stabilizes the streambanks and reduces input of fine inorganic material, the frequent freshets which occur in Carnation Creek would effectively remove much of the fine material from the streambed and help to restore it to the prelogging condition.

The increased solar radiation which reaches a stream after canopy removal may result in increased periphyton production. Gregory (1980), Lyford and Gregory (1975), and Murphy and Hall (1981) found higher biomass in clear-cut logged sections of several Oregon streams than in adjacent unlogged sections and attributed it to higher average light intensities. However, after logging of the Carnation Creek watershed, chlorophyll concentrations in adjacent shaded and unshaded areas remained similar (J. Culp, pers. comm.). The higher accumulation rates which on occasion occurred at some sites after logging ,we believe, cannot be attributed to the increased light intensity.

The increased dissolved nitrate concentrations which occurred in Carnation Creek after logging and slash burning have been observed in a number of other studies (Brown *et al.* 1973; Likens *et al.* 1970). However, Stockner and Shortreed (1978) found that increased nitrate concentrations had no effect on either periphyton biomass or species composition in wooden troughs carrying Carnation Creek water. It is unlikely that the nitrate increases after logging would have any detectable effect on periphyton in the stream.

Postlogging increases in dissolved phosphorus concentrations were found mainly during freshets, times when scouring of the streambed (and of the samplers) precluded any periphyton response to increased nutrient concentrations. However, the well-documented rapid uptake of phosphorus by algae (Gregory 1978; Lean and Nalewajko 1979; McColl 1974) may have prevented the detection of increased phosphorus inputs during low-flow periods. For this reason, the phosphorus data do not conclusively demonstrate unchanged phosphorus inputs during low-flow periods.

Stockner and Shortreed (1976) hypothesized that phosphorus was the primary factor limiting algal growth in Carnation Creek and later demonstrated (Stockner and Shortreed 1978) that additions of phosphorus alone and additions of phosphorus and nitrogen combined increased periphyton biomass. The limited periphyton response to the large changes in some environmental factors (light and nitrate) which occurred after logging tends to support the initial hypothesis that phosphorus is the major factor limiting algal growth in Carnation Creek. It is probable that the occasionally higher periphyton biomass after logging occurred in response to higher phosphorus inputs at low flow and that these higher inputs went undetected because of rapid algal uptake rates.

In a number of Oregon streams, filamentous green algae were more common in clear-cut logged sections of stream than in adjacent unlogged sections, although diatoms remained the dominant taxon in all areas (Lyford and Gregory 1975). In this study also, filamentous green algae were relatively more common after logging than before. The similarity of the filamentous green response to logging, despite widely different water chemistries (Lyford and Gregory 1975, reported phosphorus concentrations from 10 to 200 times higher than those in Carnation Creek), is evidence of their greater affinity for high light intensities than other algae commonly found in streams. Since numbers of filamentous greens were underestimated by the type of samplers used in this study, increases in periphyton biomass after logging were, as previously stated, likely underestimated to some extent.

Detected changes in the periphyton in Carnation Creek were twofold. The first was increased biomass and accumulation rates on some occasions at some sites, most likely as a result of phosphorus inputs which were higher during portions of the postlogging period. Second, as a result of higher light intensity, filamentous green algae became more abundant, although diatoms remained the dominant taxon. In future, as nutrient concentrations in the creek return to prelogging levels, periphyton production will return to lower prelogging levels as well. In addition, as streamside vegetation becomes reestablished and light intensities decrease, filamentous greens will become less abundant.

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EFFECT OF SUBSTRATE AND DETRITUS MANIPULATION ON MACROINVERTEBRATE DENSITY AND BIOMASS: IMPLICATIONS FOR FOREST CLEARCUTTING

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INTRODUCTION

Low-order (*sensu* Strahler 1957) streams draining northern temperate forests receive a significant portion of their total energy budgets from deciduous and coniferous leaf litter (Fisher and Likens 1973; Cummins 1974). Clearcutting of the forest without leaving buffer zones along the streambank will substantially decrease leaf litter input to the stream and, thus, dramatically alter the stream's energy budget. Since the macroinvertebrate communities of these streams utilize this particulate leaf litter (i.e., detritus) as an important food source (Vannote *et al.* 1980), post-logging reductions in leaf litter input and detritus in the stony substrate may decrease macroinvertebrate densities.

Even though the reliance of these macroinvertebrate communities upon particulate detritus has been widely demonstrated (Minshall 1967; Mackay and Kalff 1973; Cummins 1974), a detailed understanding of how detritus composition and quantity may affect macroinvertebrate distribution and abundance is lacking. This is largely because macroinvertebrate distribution and abundance is correlated with several interrelated parameters, including substrate composition (Linduska 1942; de March 1976), current velocity (Minshall and Minshall 1977), and organic detritus (Egglishaw 1964). Current velocity and substrate composition reciprocally influence one another, and both parameters can affect the quantity and particle-size range (i.e., composition) of the detritus trapped within the substrate (Rabeni and Minshall 1977).

Several researchers have attempted to determine the importance of substrate by controlling current velocity and varying substrate composition between treatments (Allen 1975; Minshall and Minshall 1977; Williams and Mundie 1978; Williams 1980; Reice 1980). However, the influence of detritus on the results of these studies cannot be determined, since detritus accumulation was either not measured or measured but not experimentally controlled. In studies where both substrate and detritus composition were experimentally manipulated (Mundie *et al.* 1973; Rabeni and Minshall 1977; Peckarsky 1980), either fine particulate organic matter (FPOM) was not measured, unknown dry weights of coarse detritus were added, or experimental conditions were drastically altered due to detritus accumulation during the experiment.

Since logging can affect substrate and detritus composition, field manipulative experiments were designed to examine the following questions:

1. Does substrate size and heterogeneity influence macroinvertebrate distribution and abundance if detritus quality and quantity are controlled?
2. Can changes in detritus quality and quantity within a standardized substrate composition affect macroinvertebrate distribution and abundance?

By manipulating these interrelated variables in separate experiments, a more accurate prediction of the effects of logging-related changes in substrate composition and detritus standing crop could be achieved.

METHODS

Experiment I:
Variable Substrate With Fixed Detritus

Substrate was obtained from the streambed and six treatment mixtures were produced: (I-S) homogeneous small stones (9.5 mm to 16.0 mm); (II-S) homogeneous medium stones (16.0 mm to 31.5 mm); (III-S) a 1:1 small to medium volumetric mixture; (IV-S) a 1:1 small to medium mixture with the interstices filled with fine (1.0 mm to 9.5 mm) substrate; (V-S) an identical mixture to treatment IV with additional large (50 mm to 80 mm) rocks on the surface; and (VI-S) treatment III-S with no detritus.

Alder leaves were collected from trees that had been felled five weeks earlier. The leaves were incubated for four weeks in flowing creek water free from invertebrates and sunlight. Immediately prior to experiment initiation, the conditioned leaves were ground in a blender and wet-sieved into fine (230 µm to 850 µm) and coarse (850 µm to 2000 µm fractions. Four plastic containers (0.015 m^2) with 230 µm mesh sides were filled with the appropriate substrate mixture for each treatment, and the wet weight equivalent of 1.5 g dry weight of alder detritus (coarse to fine particle ratio, 1:2) added to each container. Containers were buried 6.5 cm into a riffle substrate, the upper edges flush with the streambed surface. After a thirty-day colonization period (July 21 to August 21, 1980), animals and detritus were preserved in 10% formalin, the animals picked at 12X magnification, and the number of individuals and biomass (dry weight) determined for each taxon. Four sediment traps (0.005 m^2) per treatment were placed into the streambed during the same period to measure fine substrate movements.

Experiment II:
Variable Detritus With Fixed Substrate

Four detritus treatments were used: (I-D) no detritus added; (II-D) low hemlock detritus (1.0 g dry weight equivalent); (III-D) low alder detritus (1.0 g dry weight equivalent); and (IV-D) higher alder detritus (2.0 g dry weight equivalent). Substrate composition in the five replicates per treatment was a 1:1 small to medium mixture as in III-S. Alder and hemlock detritus were produced as outlined above, except that hemlock needles were collected after abscission. Containers were removed from the stream after thirty days (July 28 to August 28, 1980) and subsequently treated as described for the substrate experiment.

Measurement of
Leaf Litter Input

Leaf litter was sampled at each sampling site by placing five 0.25 m x 0.25 m square wooden containers with perforated (< 500 µm) polyethylene bases under the riparian (i.e., streambank) vegetation approximately one metre from the streambank (Neaves 1978). As observations of the traps during high winds (20 to 80 km/h) confirmed the effectiveness of leaf litter retention, the traps were emptied at monthly intervals from May 1 to October 1, 1980 and semimonthly from October 1, 1980 to April 30, 1981. In the laboratory, the litter was divided into deciduous and coniferous components, dried at 60°C for 48 hours, and the dry weights determined.

RESULTS

Experiment I:
Variable Substrate

Although the five substrate compositions used in the experiment covered the range from homogeneous small rocks (I-S) to a heterogeneous substrate mixture similar to the natural streambed (V-S), the density and biomass of Ephemeroptera (mayflies) and Chironomidae (midges) of the treatments were not significantly different (Fig. 1a, b). However, the homogeneous medium rocks (II-S) retained less detritus than the other substrates, resulting in a significantly lower biomass and abundance of *Baetis tricaudatus* Dodds (Ephemeroptera) and *Thiennemannimyia* group (Chironomidae). The most pronounced differences of the experiment are attributed to the no detritus treatment (VI-S), which had significantly lower Chironomidae and Ephemeroptera abundance, and a greatly reduced Chironomidae biomass (Fig. 1a, b).

Experiment II:
Variable Detritus

The effects of four quantities and qualities of detritus (I-D to IV-D) on macroinvertebrate colonization are plotted in Figure 2a, b. Relative to the control (I-D)

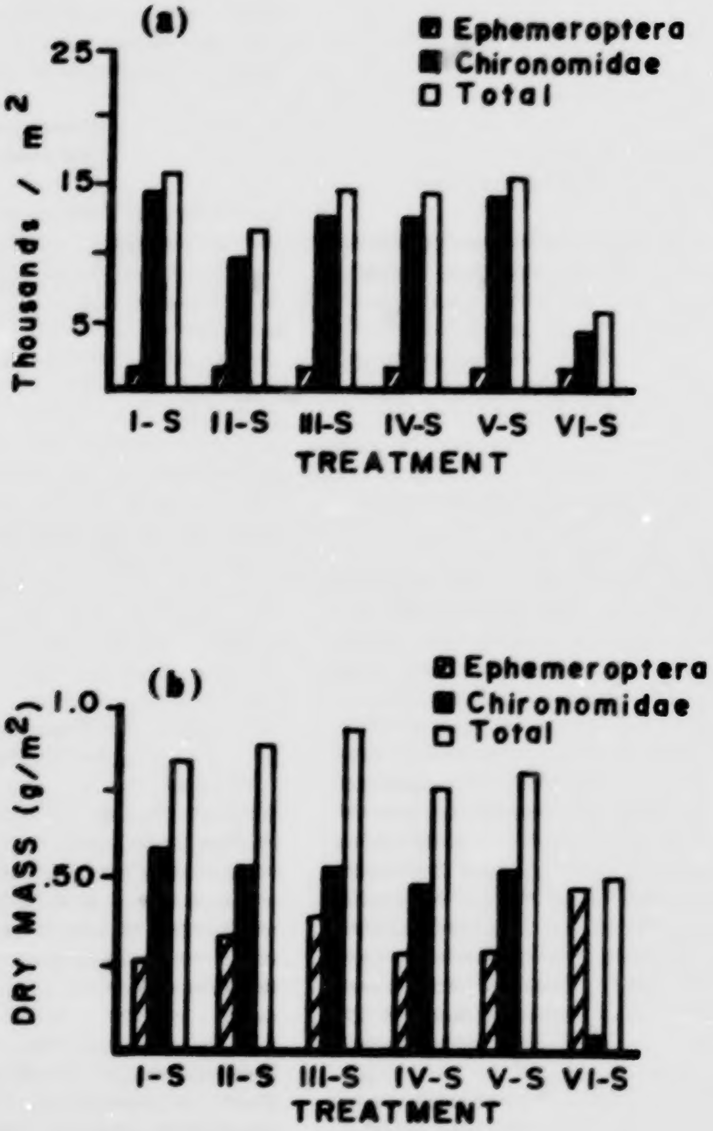

Fig. 1. Total, Chironomidae, and Ephemeroptera:

(a) density (numbers/$m^2 \times 10^3$)
(b) biomass (g/m^2 dry weight)

colonizing substrate treatments I-S to VI-S.

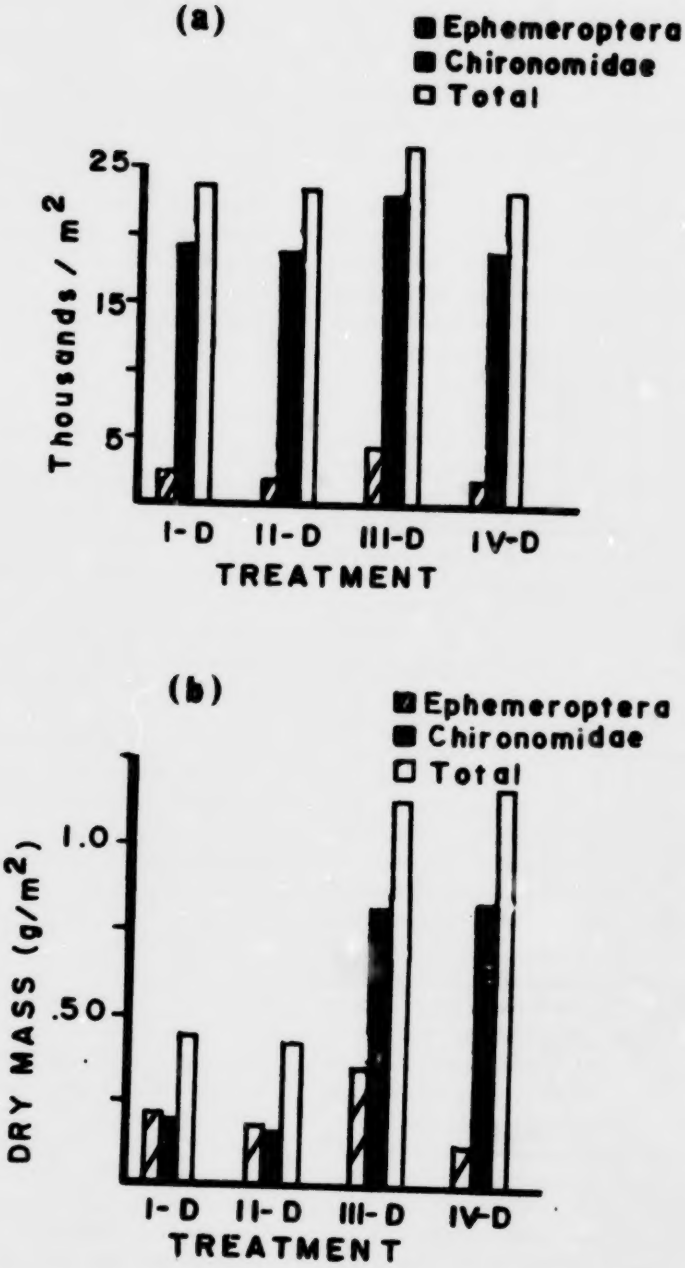

Fig. 2. Total, Chironomidae, and Ephemeroptera:

(a) density (numbers/$m^2 \times 10^3$)
(b) biomass (g/m^2 dry weight)

colonizing detritus treatments I-D to V-D.

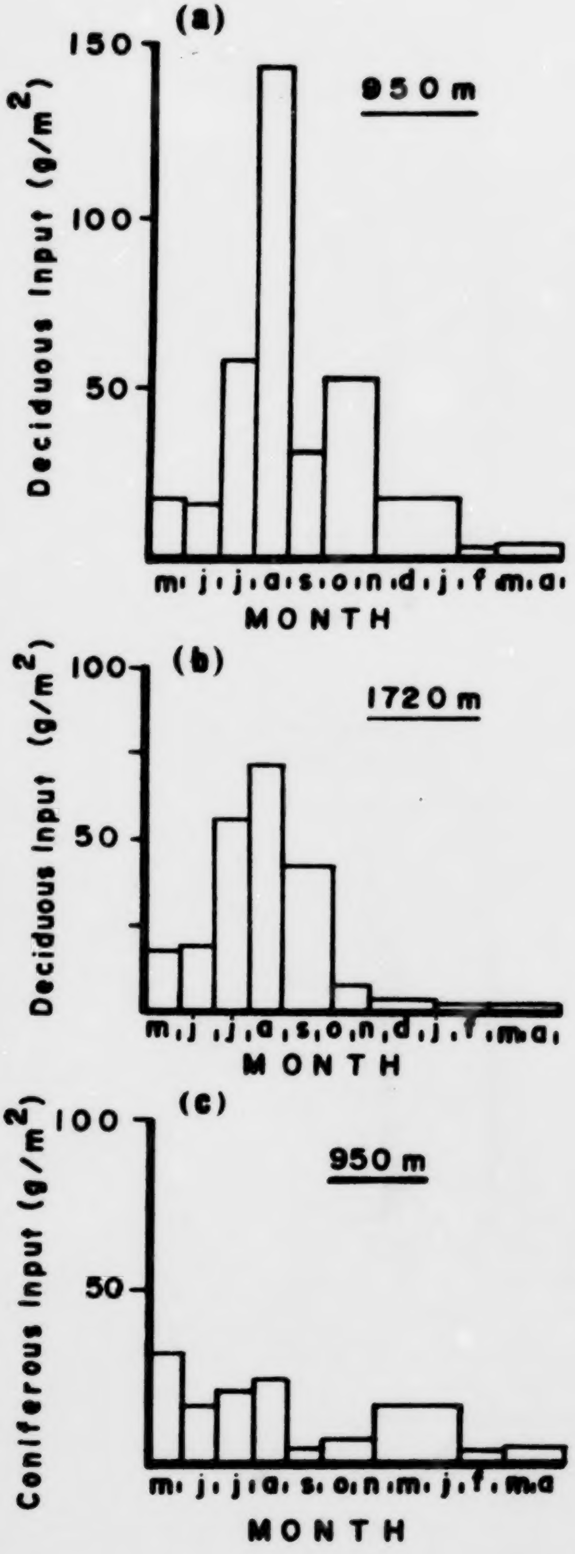

Fig. 3. Seasonal leaf litter input (g/m^2) to logged stream reaches of Carnation Creek, B.C., with undisturbed (950 m) or disturbed (1720 m) riparian vegetation.

(a) Deciduous input to 950 m.
(b) Deciduous input to 1720 m.
(c) Coniferous input to 950 m.

No coniferous input occurred at 1720 m.

with no detritus, Ephemeroptera density and biomass was significantly increased in the low alder treatment (III-D), but was reduced in the high alder treatment (IV-D). *Baetis tricaudatus* replaced *Cinygmula reticulata* as the dominant Ephemeropteran when alder detritus was present in the substrate. Chironomidae biomass was significantly higher in the alder treatments compared to the control, and densities were significantly increased in the low alder treatment, but not by high alder (Fig. 2a, b). Hemlock detritus (II-D) additions significantly decreased Ephemeroptera density (Fig. 1a), but did not affect Ephemeroptera biomass (Fig. 1b) or Chironomidae density and biomass (Fig. 2a, b).

Leaf Litter Input

Figure 3a, b, c, illustrates the coniferous and deciduous leaf litter input at two sites on Carnation Creek: (1) 950 m, a logged stream reach with riparian vegetation intact; and (2) 1720 m, a logged reach clearcut to the stream's edge. Deciduous input was highest from July through October at both sites, the peak input coinciding with hot, dry weather in August (Fig. 3a, b). The amount of deciduous input at 1720 m was greatly reduced (Fig. 3c), relative to 950 m (Fig. 3b), because of the previous removal of all riparian vegetation during the winter of 1977. Coniferous input at 950 m ranged from 5 g/m^2 in September to 31 g/m^2 in May and showed no seasonal trend (Fig. 3c). No coniferous input occurred at 1720 m.

DISCUSSION

Field manipulative studies which have shown substrate composition to affect macroinvertebrate colonization have not measured the potential influence of detritus on their findings (Allen 1975; Minshall and Minshall 1977; Williams and Mundie 1978; Williams 1980; Reice 1980). In the present study, the quality and quantity of detritus of each substrate treatment was controlled, and macroinvertebrates did not differentially colonize substrates. Since the range of substrates tested brackets the major portion of the pre- and postlogging substrates of Carnation Creek, it is not likely that logging-related substrate changes have a great effect on macroinvertebrate density or biomass. However, increased fine sediment (< 2 mm) inputs during high discharge may reduce benthic density (Culp 1982).

Experimental manipulation of detritus quality and quantity significantly affected macroinvertebrate density and biomass. Alder detritus had the greatest effect, with the biomass and density of *Baetis tricaudatus* and the Chironomidae greatly enhanced by the addition of alder detritus. Conversely, hemlock detritus was a poor-quality food source and supported Ephemoroptera and Chironomidae densities and biomasses equal to or less than those of the control treatment with no detritus. Since *Baetis tricaudatus* (Ephemeroptera) and the Chironomidae are the numerically dominant component of the drift in Carnation Creek (Culp 1982) and since the macroinvertebrate drift is an important food source for salmonids (Mundie 1971, 1974), alder leaf litter must play an important role in stimulating coho fry production through benthic production increases.

Clearcutting of the forest to the stream's edge greatly reduced deciduous input and eliminated coniferous litter input to the stream during at least the first three years after logging (Fig. 3a, b, c). Stockner and Shortreed (1978) indicate that stream algal production will increase after logging, and it is possible that the algal production will counterbalance the losses of leaf input. Although streamside vegetation may inhibit algal production by reducing the photosynthetically available light, logged stream reaches with (1720 m) or without (950 m) riparian vegetation removal had similar algal biomass in Carnation Creek (Culp 1982). By leaving streamside vegetation intact, the benthic communities receive not only the significant energy inputs from leaf litter but also substantial subsidies from algal production. Additionally, the riparian vegetation helps prevent the input of fine sediments (< 2 mm) by stabilizing the streambank during high discharge (Culp 1982). In order to maximize the energy input to the benthic community and coho fry production after logging, riparian vegetation should not be disturbed by logging practices.

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QUESTIONS
TO J. CULP

Question *(Jack Louie)*: In the discussion on leaf litter and the importance of maintaining leave strips on the streamsides, there was a suggestion that alder was important. What is the role of salmonberry in the production of such litter?

Answer *(J. Culp)*: In the data I presented, I was concerned with deciduous plant litter, so I was measuring not only alder but also salmonberry and other deciduous input. Indeed, a lot of the input which I measured was salmonberry. However, due to time constraints in my study, I didn't separate things. Phil Neaves has done leaf litter input work; maybe he can comment on that. But I would suggest that as long as you leave enough strip to allow the banks to be stable and to allow some input, that's probably enough. Now, if you want to do a really neat little study, you might look at several streams. Litter input may vary from stream to stream with the topography of the stream, the wind patterns, and such. It is a difficult question to answer directly, but I think you could get a handle on it if you wanted to actually go out and do the detailed measurements of litter input. I hope that answers some of your questions.

Question *(unidentified)*: In other words, it doesn't really matter whether it's salmonberry or alder or blueberries or poplar, whatever?

Answer *(unidentified)*: Well, no, I'm sure that it does matter to a certain degree. All I have done in my experiments is the mixture of alder, salmonberry, blueberry, etc. But, I would predict that other deciduous leaves would break down just as fast as alder. And I think the important point to remember is that in a stream like Carnation Creek, where you have this rapid flushing, the deciduous leaves and litter can be a very important component because it can break down rapidly. It doesn't have to be in the stream for a year, like hemlock for example, before it's conditioned enough to be utilized. So, I think the main point is that deciduous litter has to come in. With new species, the rates of decomposition will vary, but generally, deciduous litter breaks down rapidly.

Comment *(G. Hartman)*: I think another point is, and Joseph alluded to it, that, if it's an alder that is standing by the bank, it's not only depositing litter but it's also beginning to reconsolidate the bank, if there is any tendency for bank erosion. If it's a large tree that has been left and is reasonably stable, it will serve to maintain the bank. When we go out on field trips with your people, foresters, we can show you where new alder is coming in, laying down very substantial root systems, and tying down gravel bars. Where old alders have been left, the bank integrity remains.

Question *(D. Handley)*: I'd like to ask Joseph Culp whether, in your experiments with the hemlock and alder litter, you did do any kind of analysis of the litter itself in terms of its potential nutrient value? Do we know anything about the nutrient values of litter?

Answer *(J. Culp)*: I haven't done that in particular, but there are studies from researchers in Oregon and Idaho in the literature that we could look at. I haven't taken it to that detail yet.

Comment *(J. Hall (?))*: Well, I might just comment on that briefly, Dave. Especially as it relates to alder. Alder is a particularly valuable litter because its nitrogen content is substantially higher than that of hemlock or Douglas-fir. On the other hand, alder is lower in lignin than hemlock and Douglas-fir litter, which takes quite awhile to be conditioned by the stream microorganisms until those conifer needles are available. The interesting thing, when you start looking at this mix of deciduous and coniferous litter, is that the deciduous stuff, particularly the alder, is available right away; the coniferous stuff takes three to six months to be conditioned. So as a result, you have a fairly continuous supply of nutrients, of food available to shredder organisms throughout the year. When you have this mix of deciduous and coniferous material, there is a substantial difference in quality and insect growth rate on these different kinds of material. And alder is really about the best-quality food of any of the stuff that we've looked at.

Question *(D. Handley)*: You have done comparisons then with salmonberry?

Answer *(J. Hall (?))*: Yes. Quite a bit of chemical and physical data on the quality and chemical quality of these different kinds of litter.

Comment *(J. Culp)*: One other point, regarding a lot of the deciduous litter that is found along the floodplains, is that storms in the winter will tend to wash it in and out so you're not just getting the input in the summer, as I presented. You will get input from material that's been laying on the banks all through the winter.

Question *(T. Northcote)*: Joseph, is there any possibility that the containers that you used for your different particle size and implants in the substrate acted as differential collectors of debris as it was swept down the stream?

Answer *(J. Culp)*: Yes, I think it's very important to find out when you're doing field manipulative experiments that the conditions you set up as treatments are not overridden by natural events. We checked for that and the deposition was less than 2% as far as we could determine; so there was minimal deposition in the apparatus, mainly because we were working in low periods when there was not much organic material and the amount of sediment that actually came in was minimal also. So that wasn't a problem.

Comment *(Ed Packee)*: I'd like to go back with this matter of alder and its importance to the nitrogen source to the stream. Recognizing first of all that alder is a nitrogen fixer. But there are many stream ecosystems in which a nitrogen fixer, i.e., alder or high nitrogen litter content situation, doesn't exist. And in many cases, these streams are supported by cottonwood or aspen. I'm just wondering if this is to our advantage, because the literature that I have seen on aspen and cottonwood suggests that it is much higher in phosphorus and there were indications given here that phosphorus may actually be a limiting factor in streams such as Carnation Creek. If we want to increase the productivity, litter which is higher in phosphorus might be a good tradeoff for something with very high nitrogen and low phosphorus. Has anybody looked at that?

Answer *(G. Hartman)*: No, we haven't looked at that as far as I know. I would like to add a question: Could you get those other species to grow in habitat such as Carnation Creek?

Comment *(Ed Packee)*: I've got 100 foot or 100 year-old cottonwoods that are 5 feet in diameter on Taylor River and on the Cameron River and I see no reason why we can't use it over there. There's absolutely no evidence to suggest we can't.

Comment *(Unidentified)*: There is one contribution of alder that we didn't even discuss here. It is the association of insects with that particular species. Now these are insects that would be of potential value as fish food. The terrestrial insect component is very important to coho later in the summer when the stream levels are lower and the emergence of aquatic insects has slowed down. Next to willow, alder has the largest variety and numbers of types of insects associated with it, as potential food organisms, of any of the deciduous types of vegetation.

Question *(Unidentified)*: Regarding litter again within the three control (?) sections, did you actually measure the amount of particulate matter in the substrate before and after logging in the three sections?

Answer *(J. Culp)*: I didn't mention that today as a point; actually I slipped over it quickly because of time. However, if you look at the particulate ratio, the coarse to fine ratio, what you'd expect after logging is a decrease in the amount of coarse particulate matter, which is what you find. When you compare the amount of detritus in grams per square metre, at those two sites, one with very little litter input and also a very small amount of detritus in the substrate (now I haven't got to the point where I have it all analyzed), but what I would also expect is that the composition of invertebrates at those sites would reflect that.

CARNATION CREEK WATERSHED PROJECT FRESHWATER SCULPINS: GENUS *COTTUS* A REVIEW

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ABSTRACT

Extensive information on population dynamics, migratory movements, growth, and food habits of *Cottus asper* and *C. aleuticus* in Carnation Creek are given. Field observations and controlled experiments indicate that sculpins do not, through competition, produce adverse effects on young coho salmon at the population densities normally encountered in the stream.

Data from the study do not demonstrate impacts of logging treatments on sculpin populations. Population estimates and counts of migrating fish were not sensitive or reliable enough to reveal impacts of logging on fish populations if such impacts had occurred.

INTRODUCTION

In the late 1960s and early 1970s, the British Columbia Forest Service referral system and guidelines for logging were having limited success in reducing forestry-fisheries conflicts. As well, the forest service's coast logging guidelines implemented in 1972 were claimed to be producing major economic hardship under present market conditions for the forest industry. The realization of the need to both understand the relationship between logging and the natural watershed ecosystem combined with the need for integration of the management of watershed resources led, in part, to the establishment of the Carnation Creek Watershed Project in 1970. The objective of this study was (Narver and Chamberlin 1976):

To develop a better understanding of how undisturbed coastal rain forest salmonid stream ecosystems work in order to:

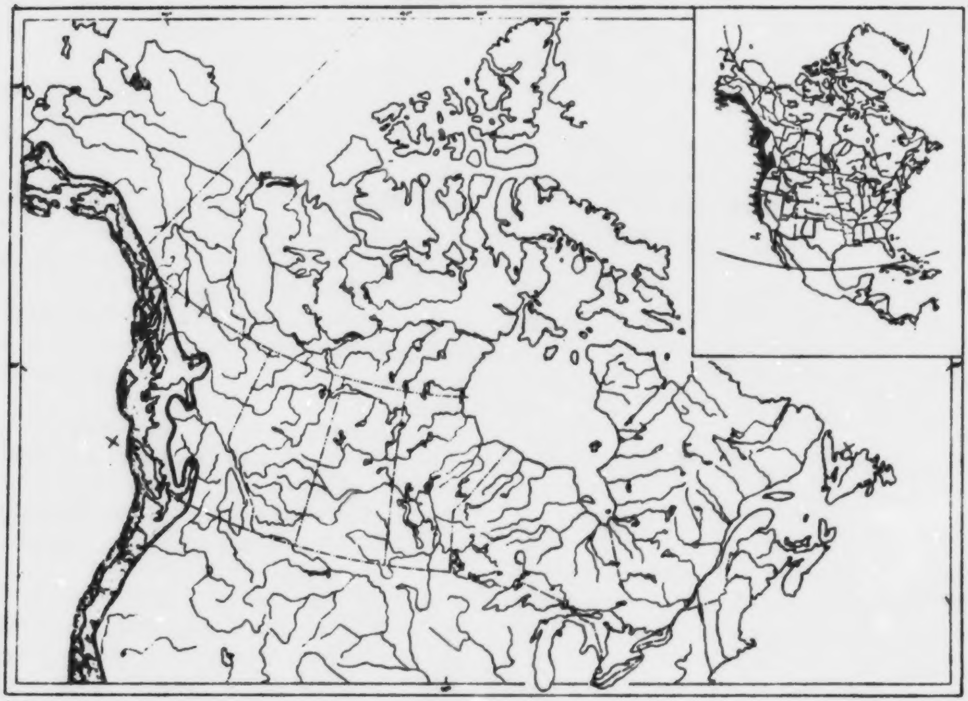
a. Explain and quantify in sufficient detail the impacts of timber production and forest management activities on stream environments and their capacity to produce salmonid fishes.

b. Provide input to the continued development of sound, practicable, integrated resource management guidelines for the watershed ecosystem.

A primary concern with forest harvest impacts has centered on the salmonid species. However, many small coastal streams in British Columbia, which are important spawning and nursery areas for salmonids, also contain resident populations of sculpins (family Cottidae, Genus *Cottus*). As benthic foragers, sculpins occupy space and consume food items that are also accessible to salmon and trout. Although of no direct commercial value, high sculpin densities suggest an integral role in stream ecosystems. Of the eight currently identified freshwater species in North America, five occur in the Pacific Northwestern United States, British Columbia, and Alaska. Of these, the coast range sculpin *Cottus aleuticus* Gilbert and the prickly sculpin *Cottus asper* Richardson are the most widely distributed and abundant in coastal stream systems (Fig. 1).

Research on the ecological role of sculpins in Northwestern North America has generated numerous conclusions about their relationships in stream eco-

Cottus aleuticus



Cottus asper

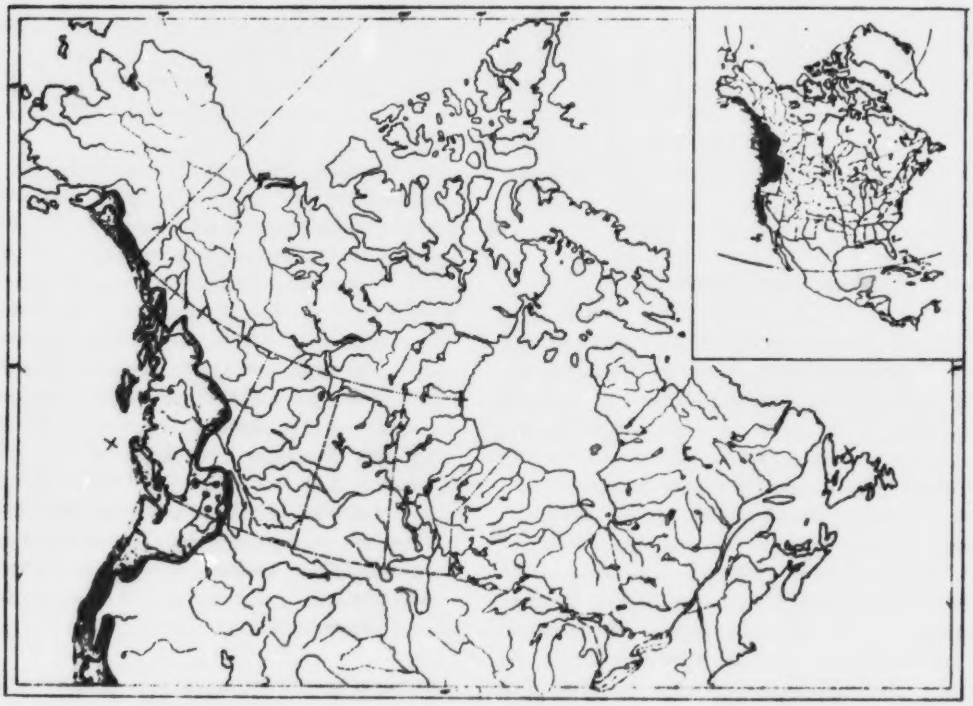


Fig. 1. Distribution of *C. aleuticus* and *C. asper* in the Pacific Northwest and British Columbia.

systems. A literature review by Ringstad and Narver (1973) indicates that, while members of this genus are capable of consuming large quantities of salmon eggs and fry, they are probably not a significant factor in egg survival or juvenile salmonid production in natural coastal stream systems. Moyle (1977), in a more recent literature review, describes the relationship between sculpins and salmonids with respect to predation and competition for food. Moyle concludes:

> "The limited evidence available indicates that sculpins can severely limit salmonid populations through either predation or competition only under exceptional or artificial conditions. Probably the most severe damage by sculpins takes place in situations where man had already badly damaged the salmonid populations through overexploitation or environmental disturbance. Obviously more definitive work needs to be done on sculpin-salmonid interactions in streams, particularly in natural or near-natural situations, before sculpins can be condemned as being responsible for salmonid declines."

The literature to date remains inconclusive as to the impact of sculpins in natural-stream ecosystems. Current attitudes still range from sculpins being considered potentially serious competitors, thus lowering stream production of salmonids, to their being net benefitors to salmonids, acting as alternate prey for larger salmonids and other natural predators on fish.

Preliminary assessment of the fish species composition and abundance in Carnation Creek indicated high densities of sculpins relative to juvenile coho salmon and steelhead trout. Sculpin densities ranging from 33% to 66% of total late-summer fish biomass were recorded. Greatest sculpin abundance occurred in the lowest part of the stream (Ringstad and Narver 1973). Thus, determining the role of sculpins in the ecology of Carnation Creek was considered an important component of the watershed study.

In the context of the foregoing, the objectives of this paper include:

1. Describing the biology and life history of *Cottus aleuticus* and *Cottus asper* with respect to the Carnation Creek watershed.
2. Attempting to explain the 10 years of cottid population and migration data as they relate to:
    a. Natural fluctuations
    b. Watershed-calibration effects
    c. Logging-treatment effect
3. Discussing data limitations relating to further analysis.

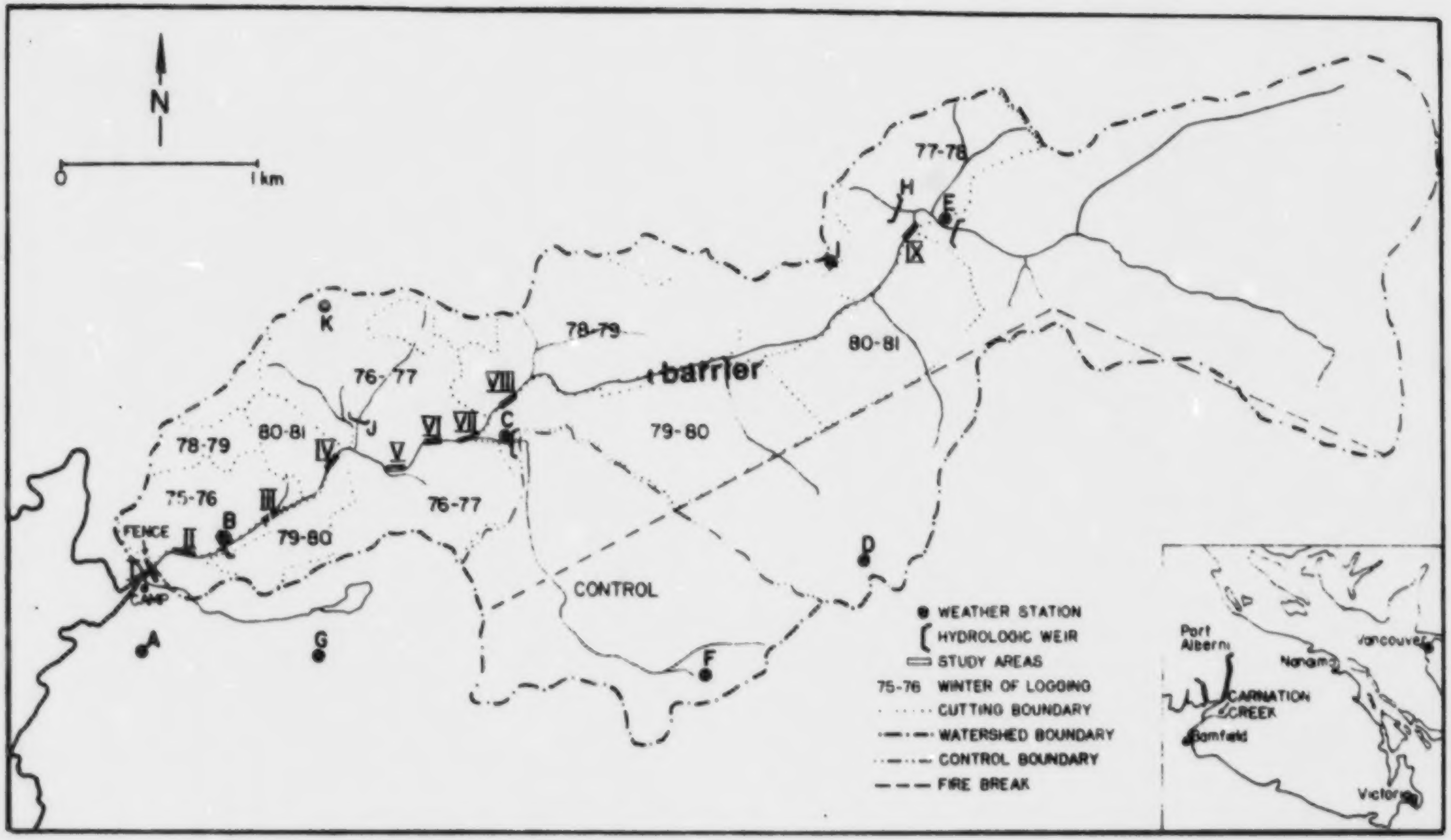
This document is not intended to be complete or comprehensive, but rather a summary of sculpin data and information which may lend itself to further analysis as the results of other components of the watershed study become available.

THE STUDY AREA

Carnation Creek, typical of most Vancouver Island west coast streams, consists of a high ratio pool to riffle complex. The lower reaches form a 200 m long, low-gradient, gravelly estuary and tidal mud flats. The stream has a highly variable discharge which, prior to logging, reached a maximum of over 35 m^3/s ($>$ 1200 cfs) during intense winter and spring rainfall. In the late summer, discharge reached a minimum of < 0.02 m^3/s (0.7 cfs), at which time the flow in the lowest section (0 m to 500 m) and the upper section (2500 m to 3100 m) became subsurface, leaving large isolated pools. Only the lower 3070 m of Carnation Creek are accessible to anadromous salmon and trout because of an impassable natural barrier preventing further upstream movement (Fig. 2). The fish complex of the lower 3070 m is comprised of chum (*Oncorhynchus keta*), coho (*O. kisutch*), steelhead (*Salmo gairdneri*), cutthroat (*S. clarki clarki*), coast range sculpin (*Cottus aleuticus*), and prickly sculpin (*C. asper*). The staghorn sculpin (*Leptocottus armatus*), a marine species, is resident in the lower section of the estuary. Above the natural barrier, cutthroat trout is the only fish species present.

BIOLOGY OF SCULPINS: GENERAL OBSERVATIONS AND DISCUSSION

The coast range and prickly sculpins are the only two species of freshwater sculpin on Vancouver Island and the only two species to have a pelagic larval stage in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STUDY AREAS
75-76 WINTER OF LOGGING
CUTTING BOUNDARY
WATERSHED BOUNDARY
CONTROL BOUNDARY
FIRE BREAK
Port Alberni
Nanaimo
Vancouver
CARNATION CREEK
Bamfield
Victoria

Fig. 2. Map of Carnation Creek watershed.

their life cycle. The following description and discussion of aspects of the biology and life history of sculpins are taken from Ringstad and Narver (1973), Ringstad (1974), and unpublished data and information collected during the Carnation Creek Watershed Study.

Distribution

The prickly sculpin is most abundant in the upper reaches of the Carnation Creek estuary and in the lower reaches of the stream up to approximately 1500 m. A few large individuals are found as far as 2000 m upstream. The coast range sculpin is distributed throughout the stream up to 3070 m. Both species are found on the stream bottom and display benthic microhabitat behavior.

During late summer, *C. aleuticus* (40 mm to 65 mm size range and 1 to 3 years old) in the lower sections of Carnation Creek are located primarily in the head and tail areas of shallow riffles. Larger individuals (> 60 mm, ≥ 4 years old) are found in deeper water where logs, boulders, and overhanging vegetation provide cover. Occasionally, *C. aleuticus* and *C. asper* (> 60 mm) are found together in pools, though *C. aleuticus* is always located in areas of higher current velocity. *C. asper* is found mostly under cutbanks, logs, and debris in low water velocity or near the tail end of pools.

In the upper section of the stream, *C. aleuticus* (> 70 mm) is usually confined to the head and tail sections of riffles. The few *C. asper* that are present are found deep under cutbanks and exposed root wads. Only *C. aleuticus* is found in open pools containing boulders and debris substrates. Above 2000 m, *C. aleuticus* occupies space under root wads, logs, and undercut banks only in the absence of *C. asper*. However, both species of sculpin have the potential to occupy similar habitats.

Population Size

Prior to the initiation of the watershed project, the population of *C. asper* is estimated to have ranged from 3500 to 4000 individuals, with the greatest abundance in the lower 1200 m of the stream. The population of *C. aleuticus* probably ranged from 8 000 to 10 000 individuals distributed further upstream than *C. asper*. These estimates are lower than those originally calculated in 1971 by the Peterson mark and recapture method. The new 1971 estimates were subjectively determined from a combination of data, information, and field experience gained during the initial years of the project.

From 1972 on, the removal method for population estimates (Seber and LeCren 1967) was employed. For all years, fish collection was by a Smith Root 400 volt pulsed DC shocker. The mark and recapture method produced inflated population estimates because catchability of marked fish in the recapture sample changed (i.e., fish avoided the sampling gear). This problem was most likely compounded by the microhabitat preferences of sculpins (i.e., rubble, undercut banks, debris, etc.) where the electroshocker could not necessarily catch or retrieve a representative sample. Mason and Machidori (1976) in a study of sympatric sculpins in several small streams on the east coast of Vancouver Island found the mark and recapture method proved fruitless because of extensive behavior changes in marked fish following their release.

Population estimates derived from the removal method, on the other hand, could be widely variable depending upon the catchability of sculpins in both the first and second pass. This was the case for several study sections in Carnation Creek in which the total number of sculpins captured was low (i.e., less than 5) and it was not uncommon to capture more fish on the second pass.

Sampling mortality may also have caused inaccuracy in population estimation; however, samples of sculpins captured by electroshocking and held for 48 hours indicated no delayed mortality.

Error associated with both population estimation methods and the fish collection methods, combined with very low numbers in the capture samples, have made accurate population estimates difficult, if not impossible, to achieve.

Natural Fluctuations In Populations

The factors affecting the size and stability of sculpin populations in natural west coast streams has not been intensively studied. The following discussion suggests three major factors which may significantly influence population size and distribution. They are habitat stability, inter- and intraspecific competition for space, and recruitment.

A primary form of sculpin habitat in Carnation Creek is the result of natural stable debris which acts not only to provide direct cover but also to stabilize the stream course. The Carnation Creek watershed, comprised of stands of mature and overmature western red cedar, hemlock, and spruce, produces a large amount of large organic material which, when in the stream as natural debris, is relatively stable (Schultz 1981). In concert with stream gravels, natural debris creates and maintains fish habitat in the form of pools, riffles, and undercut banks.

Streamflows provide the wetted area of the habitat. Thus, fluctuations in flows will not only change the amount of habitat available but also cause changes to the distribution and form of habitat.

Carnation Creek is highly responsive to rainstorm events. Substantial bedload movement takes place in the lower sections of the stream, resulting in the shifting of the gravel-cobble substrate. Although not documented, this shifting of materials may cause mortality of *C. aleuticus* individuals, especially during winter months, when they bury into the substrate. In addition, during intense spring and fall rainstorm events at which time *C. aleuticus* is restricted to areas of poor or least cover (i.e., riffles and high water-velocity areas), significant mortality may occur. Estimation of overwintering mortality was not attempted, as the reliability of population estimates is suspect and sculpin samples were not broken down by age group.

During late summer, when streamflows are lowest, sections of Carnation Creek become large isolated pools, thus presumably forcing *C. aleuticus* out of riffle areas and into pools. If "wetted" area is an important factor in regulating sculpin populations, then a relationship between sculpin biomass and streamflow may exist. Annual late-summer *C. aleuticus* biomass levels (1971 to 1981) in Carnation Creek were not positively related to minimum instantaneous stream discharge (analysis of covariance). However, this may not be surprising, considering that both species of sculpin show a significant population decline between 1971 and 1975 which cannot be explained by natural fluctuations.

Because sculpins show a strong tendency to remain on the stream bottom and under cover, or even in the substrate, competition for space with salmonids, except perhaps juvenile rainbow trout, is probably low in Carnation Creek (discussed in a later section). However, competition between species and age groups within species of sculpins is evident. As indicated, the presence of *C. asper* restricts *C. aleuticus* to the periphery of cover habitat. Within both species, the larger individuals occupy the "best" habitats. Coupled with this evidence of competition, the relative distribution of age groups, i.e., the fry of both species residing in or near the estuary until becoming yearlings, further suggests interspecific competition for space. Individuals of both species held in aquaria exhibit strong cannibalistic behavior on smaller individuals. It is considered that the segregation of adults and juveniles may have evolved to minimize predation.

The distribution of sculpins in Carnation Creek, in which the greatest biomass occurs in the lower 1500 m, suggests that upstream movement of postspawning adults and yearlings may be restricted. Mason and Machidori (1976) determined that upstream movement of both *C. asper* and *C. aleuticus* was hindered by minor obstructions in the stream. Their upstream distribution limits were marked by similar but different obstructions. It was determined that obstructions resulting in differences in water levels greater than 30 cm were impassable for *C. asper*, while differences greater than 45 cm were necessary to prevent upstream movement of *C. aleuticus*. According to Ptolomy (1982 pers. comm.), man-made barriers constructed in Colquitz Creek (near Victoria on Vancouver Island) have resulted in an accumulation of *C. asper* below the lower barrier, with only sparse biomass levels above.

The natural stable debris in Carnation Creek does result in small obstructions and waterfalls similar to those reported by Mason and Machidori (1976). This combined with the fact that gradient becomes steeper in the upstream parts of the creek probably influence the upstream distribution of sculpins. Considering the migratory behavior of sculpins, these factors probably play a significant role in population regulation.

In summary, data and information collected on sculpins suggests that their populations, although probably dynamically stable, were subject to fluctuations due to mortality induced by habitat reorganization, inter- and intraspecific competition for benthic habitat, and recruitment of postspawning adults and yearlings into the stream population.

Spawning

Both species of sculpin migrate downstream in the spring to spawn. Most spawning occurs in the lower reaches of the stream and upper section of the estuary. Part of the *C. aleuticus* population spawns upstream. Peak downstream movement of spawners occurs in March and April (Fig. 3). Movement is most intense at night. Gonad examination indicates a sex ratio of approximately 1:1 for both species. Otolith examination of these downstream migrants indicates that one-year-old fish of both species are absent. Being sexually immature, this age group would not necessarily be expected to occur in the population of spawners. Extensive seining and electroshocking in all areas of Carnation Creek show that the majority of these one-year-old fish are located in the estuary in June.

Adult male sculpins choose a nest site usually under large rocks in the lower stream or estuary. Female sculpins lay an adhesive egg mass on the roof of the nest which is guarded by the male until the eggs hatch into pelagic (free-swimming) larvae in 15 to 35 days. More than one female may lay eggs in one nest over the spawning period; thus, not all eggs in any one nest will hatch at the same time. Nests may contain in excess of 24 000 eggs (Ringstad 1974).

Larvae from eggs hatched upstream in Carnation Creek drift to the estuary at night where, along with larvae hatched in the estuary, they are active only at night during flood tide periods. It is suspected that, during the day, larvae remain in the stream substrate. Larvae metamorphose in approximately 30 days and sculpin fry begin appearing in the estuary in late July. They are approximately 10 mm in length at this time. By October, fry of both species are abundant in the estuary, where they exhibit distinct habitat preferences. *C. aleuticus* fry are found in the riffle areas buried under rocks and in coarse gravel, while *C. asper* are confined to slack water areas and back eddies.

A postspawning upstream movement of adult sculpins occurs in late summer and fall (Fig. 3). Sculpin fry of both species remain in the estuary and migrate upstream in the late summer and fall of the following year as yearlings (Fig. 4). Similar migration and distribution patterns, as those found in Carnation Creek, are reported by Krejsa (1967) and Taylor (1966) for the same species of sculpin in the Little Campbell River near Whiterock, B.C.

Age and Growth

Age determinations, based on otolith readings and examination of length-frequency distribution, indicate considerable overlap in size ranges of consecutive age groups. Ages 1 to 4 comprise the majority of the population of both species. The majority of *C. aleuticus* individuals are less than 70 mm and most *C. asper* are less than 80 mm. Ringstad and Narver (1973) describe the age and growth characteristics of both species. The mean size of *C. asper* for age groups 2 to 4 are significantly larger than those reported in the literature from Oregon and Alaska. However, the mean size of *C. aleuticus* is similar to that reported from Oregon, but smaller than those from Alaska in similar age groups (Table 1).

Diel and Seasonal Feeding

Prior to logging, both species of sculpin fed heavily on benthic insect larvae and nymphs, with maximum feeding activity during the darkest hours of the night (Fig. 5). In July, Plecoptera and Ephemeroptera nymphs were found to be the most abundant food organism in *C. alceuticus* stomachs in late evening and early morning. During the afternoon and early evening, Trichoptra larvae were the dominant food item ingested. Chironomid larvae were an important food during the late evening and early morning, but decreased in abundance during daylight hours. Simuliid larvae occurred only occasionally. A few stomachs contained large numbers of individuals of the families Halicaridae, Ixodidae, and Orobatidae.

Seasonal changes in food items consumed were evident and probably reflect the different availability of items throughout the diel feeding period (data not presented). A postlogging study of the food habitats of sculpins is not completed.

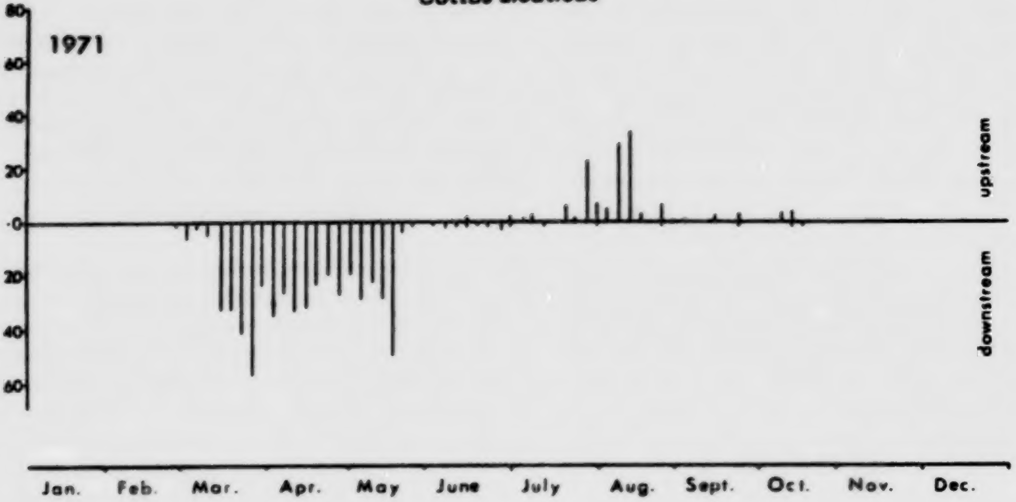
Interaction
With Other Species

In Carnation Creek, both species of sculpin occupy space and consume food items that are also accessible to, and utilized by, juvenile coho salmon and steelhead trout.

Space

Competition for space between sculpins and coho fry is minimized during the warm summer months by the fact that sculpins stay near the bottom and coho remain in midwater. In winter, coho move into tributaries, side channels, and backwaters seeking cover under logs, cutbanks, and stable debris (Bustard 1973). Some sculpins also seek cover in these areas, but the majority bury themselves in the streambed to overwinter.

Cottus aleuticus



Cottus asper

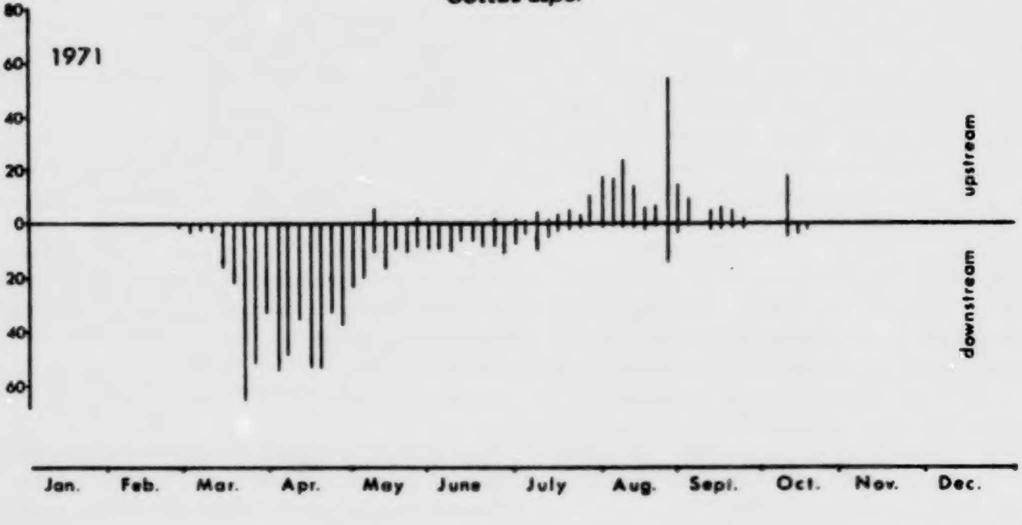


Fig. 3. Migration of *C. aleuticus* and *C. asper*, main fence.

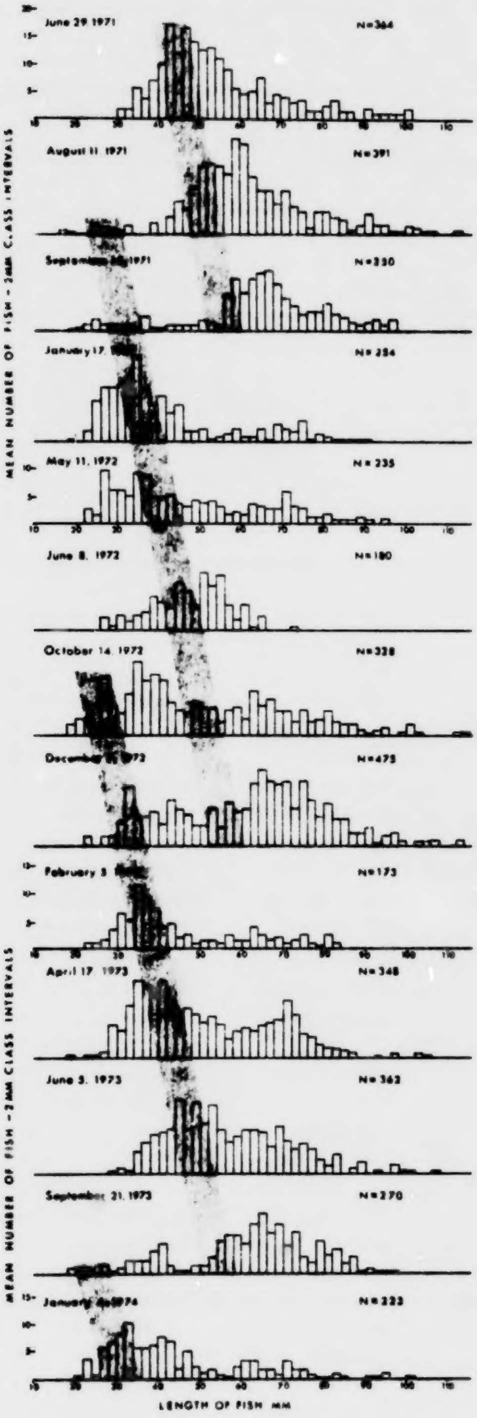


Fig. 4. Length frequency of *C. asper* in Carnation Creek estuary, 1971 to 1973.

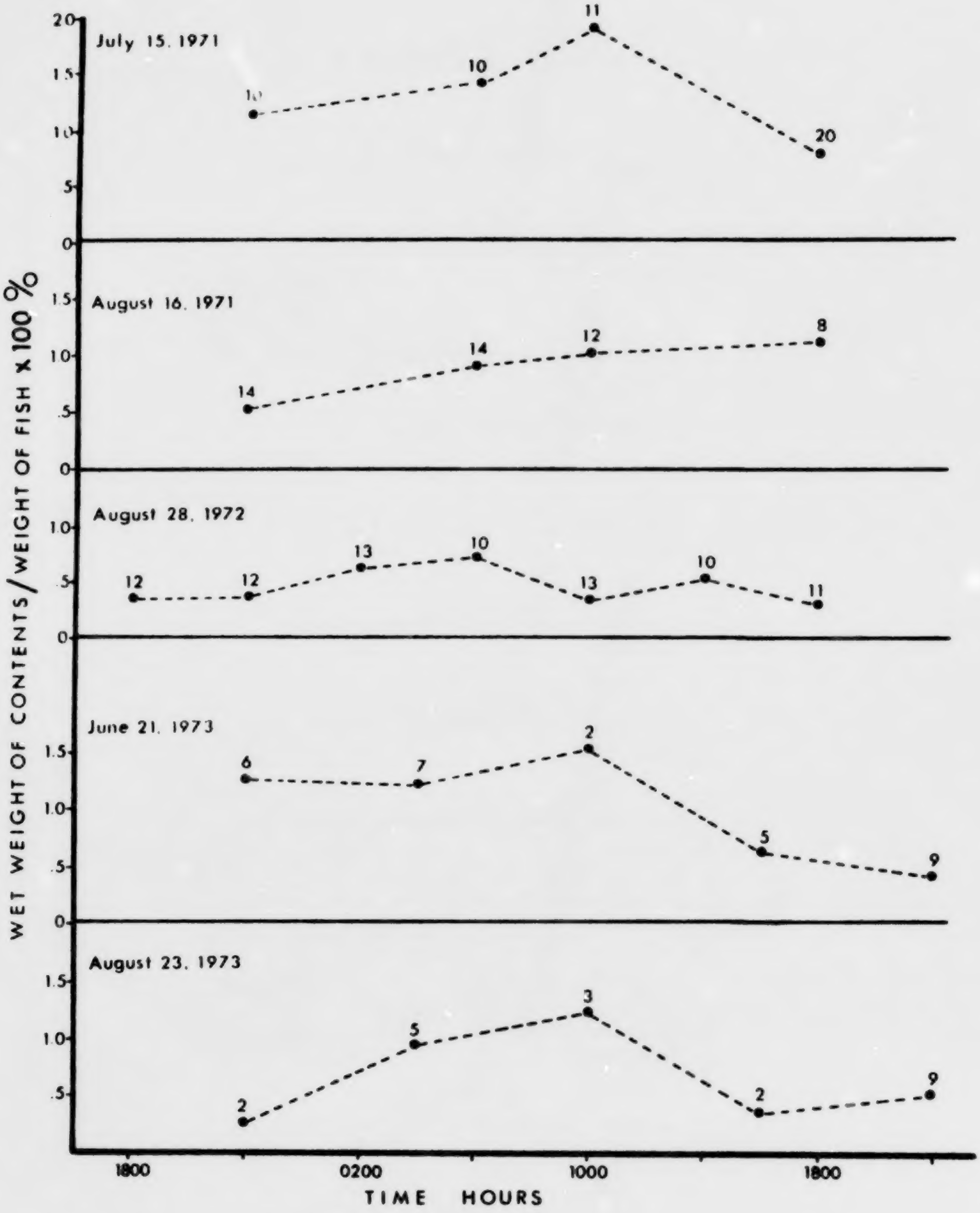


Fig. 5. Diel feeding pattern of *C. aleuticus* in Carnation Creek, 1971 to 1973.

Table 1. Mean lengths of age groups and annual relative growth rate of *C. asper* and *C. aleuticus* from the literature.

	Age Group (mm) (Annual Relative Growth %)				Time of Collection
	1	2	3	4	
Oregon					
– *C. asper*	45.7 (18.16)	54.0 (30.7)	70.6 (20.6)	85.2	?
– *C. aleuticus*	46.4 (21.12)	56.2 (23.7)	69.5 (10.8)	77.0	August
B.C.					
– *C. asper*	45.0 (44.4)	65.0 (36.0)	89.0 (10.7)	98.5	August
– *C. aleuticus*	41.5 (37.3)	57.0 (22.8)	70.0 (13.5)	79.5	September
Alaska					
– *C. aleuticus*	44.0 (18.18)	52.0 (15.38)	60.0 (16.0)	69.6	September

It is evident that some overlap may exist in overwintering space between sculpins and steelhead fry.

According to Bustard (1973), with lowering stream temperatures from 9° to 2°C, coho and older steelhead juveniles tend to move into deeper water, while most steelhead fry remain in shallow marginal sections of the stream. As water temperatures decline in the winter, steelhead fry are found most often under rubble, while coho and older steelhead are most often found within upturned roots and under logs. Stream discharge also appears to have a significant influence on fish activity, especially at water temperatures between 4° and 8°C. When streamflows are low, coho and steelhead are more inclined to hide, even though water temperatures do not change.

Competition for space between sculpins and cutthroat trout was minimized in their prelogging distribution. Cutthroat were primarily restricted to the area above the impassable barrier or to tributaries.

Predation

It is believed that sculpins do not consume large quantities of resident juvenile salmonids. The sculpin feeding surveys conducted in Carnation Creek between May and August from 1971 to 1973 showed only one sculpin stomach to contain a salmonid juvenile. However, large sculpins captured in downstream traps along with emigrating chum and coho fry during spring and early summer contained large numbers of juvenile salmonids in their stomachs. It is evident that fry consumption occurred while the fish were in the traps. Although given the right opportunity, sculpins can and will consume large quantities of salmonid fry and members of their own genus (personal observation). The downstream trap situation is unique and most likely does not represent the spatial distribution or behavior of fish in the natural environment.

Food Resources

Competition for food between sculpins and coho juveniles in Carnation Creek was thought to be a potential interaction as preliminary assessment indicated an overlap in food items consumed. Diel-feeding behavior of coho juveniles differs from that of sculpins. Coho feed in the midsurface to surface parts of the water column during evening and morning twilight when light intensities are above 0.005 fc and visual feeding is possible (De Leeuw 1981).

Sculpins feed almost exclusively on aquatic food organisms of benthic origin during the summer period of July and August. Their maximum feeding activity occurs during the darkest period of the night when stream bottom organisms are most active.

An experimental study was conducted at Carnation Creek in 1973 to determine the effect of increasing densities of sculpins on the availability of food of benthic origin and on growth of coho fry in artificial stream troughs and in-stream enclosures. The experimental design tested the hypothesis: the presence of *Cottus aleuticus* does not significantly affect the growth of coho fry (*O. kisutch*) in artificial stream troughs.

The study showed that, at natural stream densities, sculpins probably did not crop the benthos sufficiently to limit coho fry growth. This was true even though terrestrial insects, often an important component of coho diets, were excluded from the experimental troughs. However, at very high densities, *C. aleuticus* significantly reduced the amount of drifting benthos. This was, in turn, reflected in a decreased growth rate of coho fry.

The relative contributions of terrestrial and benthic organisms to the diet of juvenile coho are highly variable, subject to changing environmental conditions such as degree of stream cover, plant species composition, streamflow, proximity of coho rearing habitat, potential food supply, time of year, etc. In Carnation Creek during early summer, coho feed primarily on food items in the water column which have originated from benthos (drifting) and terrestrial sources. During late summer and minimum streamflows, coho rely heavily on food items of terrestrial sources (Scrivener, pers. comm.). Because of these complexities, the influence of sculpin presence and food consumption on coho may depend on a variety of factors.

The importance of aquatic insects as a food source for juvenile salmon has been well documented (Chapman 1966; Demorey 1961; Hoar 1942, Maitland 1965; Mounce and Mundie 1972; Mundie 1969, 1971; Narver 1972; Ricker 1937). In Oregon, Demorey (1961) showed that coho fry fed almost exclusively on midwater or surface-drifting organisms and that, in two out of three streams, aquatic insect larvae represented by the family Tendipedidae (= Chironomidae, Diptera) were the most important food items in terms of dry weight. Demorey noted that the predominance of either terrestrial or aquatic organisms was directly related to the abundance of stream cover and surface flow between pools during low summer flow. Fish fed primarily on aquatic organisms when there was surface flow between pools but were restricted to terrestrial drip when isolated in pools. Coho fed more heavily on aquatic insects in areas of the stream where overhead cover, which supplied much of the terrestrial input, was sparse or absent. Demorey also suggests the possibility of increased availability in winter of the mayfly *Paraleptophlebia* due to decreased light intensities.

Narver (1972) stated that coho and trout juveniles in two streams on the east coast of Vancouver Island relied heavily on adult and immature aquatic insects in timbered sections, but consumed more terrestrial insects in logged areas of the stream. Although Demorey's (1961) results contradict those of Narver (1972), it is conceivable that the differences were due to different species composition of the stream canopies. Narver states that, during the late summer and early fall, Diptera larvae were most important in timbered sections. Coho fry relied more heavily on terrestrial food items than did trout (*Salmo gairdneri*).

In situations such as the Carnation Creek experimental trough study where terrestrial food was scarce or absent, coho relied entirely on drift organisms originating from the benthos. Since benthic drift in Carnation Creek was mainly nocturnal in timing (Scrivener, pers. comm.), this implies that coho fry fed actively at very low light intensities in the experimental trough, i.e., at dusk and dawn.

Brett and Groot (1963) indicated that coho fry can effectively search out and feed on *Daphnia* under reduced light conditions. Inhibition of feeding occurred at 0.01 fc; a feeding rate of one-half the maximum was still possible at 19^{-4} fc, with an extinction level of close to 10^{-5} fc. Brett and Groot noted that bright moonlight was approximately 300X the extinction level. The overlap between the light intensity which initiates activity and drift of benthos and the minimum light intensity in which coho can feed strongly suggests that coho can utilize nocturnal drift. The diversity of feeding conditions which coho juveniles may experience is such that they may be affected by sculpins in one situation and not affected in another.

In the experimental trough system, elimination of terrestrial food probably artificially sharpened the competitive interaction between coho and sculpins. With terrestrial food available in the natural stream being very high, sculpin densities would be needed before coho growth would be adversely affected. Sculpin densities in Carnation Creek range from 0.01 to 3.3 fish/m^2. The maximum density used in the trough experiments was 2.5X higher than stream densities. In experiments carried out in the isolated sections of the stream, densities were 2X higher than in Carnation Creek. Several natural factors probably limit high sculpin densities. During low summer flows, at which time available habitat would be minimal and interspecific competition for food probably maximal, a high proportion of sculpins reside in the estuary. Other possible factors limiting high sculpin population levels and, hence, interaction with coho have been described.

Stream-carrying capacity for salmonids is a function of available food and space (Chapman 1966) and highly variable (Burns 1971). In Carnation Creek during low summer flow prior to logging, coho juvenile densities in pools ranged from 0.49 to 2.8 fish/m^2 (mean range 0.76 to 0.83). An unusual density in June 1972 of 4.6 fish/m^2 was recorded. Coho fry density in the experimental troughs was close to five times the mean stream density. These plus the conditions of high sculpin density in the experiment should sharpen the interaction between coho and sculpins. The lower density conditions in the stream suggest less interspecific interaction there.

In summary, there is no hard evidence to convict sculpins of having an impact on salmonid production in coastal streams via competition for space or food resources.

According to Glova and Mason (1977), results of a study on populations of sympatric and allopatric coho and cutthroat trout salmonid biomass in sympatry is higher generally than that of cutthroat only in allopatry, even when high sculpin densities are present in the sympatric situation and representing biomass greater than trout and salmon juveniles combined.

Further analysis of Carnation Creek Watershed Study data and information may provide further insight.

POPULATION AND DISTRIBUTION TRENDS (1971 TO 1981): LOGGING IMPACTS

The foregoing sections have dealt with the biology of sculpins and the biology of salmonids, with consideration of interspecific effects. These descriptions are considered, with some limitations, representative of a typical unlogged west coat Vancouver Island stream. The following section presents a summary of sculpin population, distribution, and migration data collected between 1971 and 1981 and attempts to explain trends relative to prelogging watershed calibration and logging prescription. Reliability of the annual sculpin population estimates is subject to question; therefore, only broad conclusions have been drawn.

Watershed Calibration Period (1971 to 1976)

During the prelogging period, a significant decline in the population levels of both species of sculpins occurred (Figs. 6 and 7). Although the high population estimates for 1971 are not directly comparable to other years due to the use of a different estimation technique, a downward trend is obvious. Population estimates were conducted in late summer (August-September); thus, they do not include the underyearlings or adult sculpins which have not returned upstream from spawning and are therefore most likely conservative. By 1975, the population of *C. asper* had decreased from 3500 to 4000 individuals to fewer than 150, and *C. aleuticus* numbers had declined from over 8000 to 2000.

Figure 8 shows the biomass estimates for *C. aleuticus* by study section in Carnation Creek (1971 to 1981). Population samples of *C. asper* were too low or sporadic after 1971 to determine such section estimates. During the watershed calibration period, *C. aleuticus* biomass declined in all study sections. Figure 9 shows the biomass estimates for both species of sculpin in specific study sections of the control streams: Frederick and Useless creeks and the south Pachena River. As was the case in Carnation Creek, population numbers and biomass of *C. asper* were high in 1971 and then declined in the control streams. After the rapid decline, the numbers of sculpins in these streams seemed to stabilize.

The pattern of decline in sculpin numbers, evident after 1971-1972 in population estimates, also occurs in the number of fish moving to and from spawning. The annual downstream spawning movement and upstream return of both species of sculpin are summarized in Figure 10. Although downstream counts may not be totally accurate due to reduced trap efficiency during high water, time of trap installation, etc., an obvious and dramatic decline in downstream movement between 1971 and 1975 occurred. *C. aleuticus* numbers during this period dropped from over 2500 to less than 100 and *C. asper* from over 3000 to less than 200. Data on upstream movement,

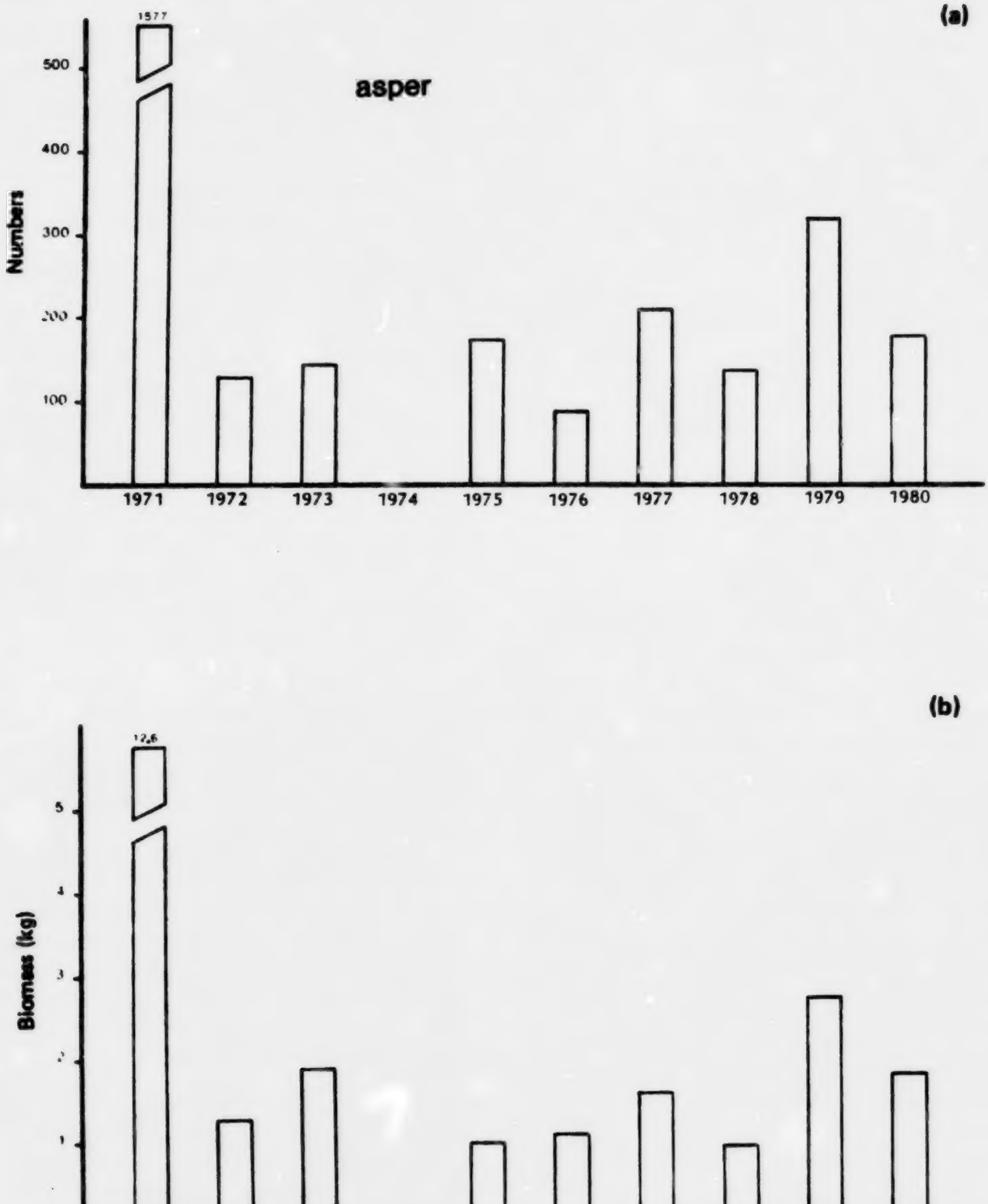
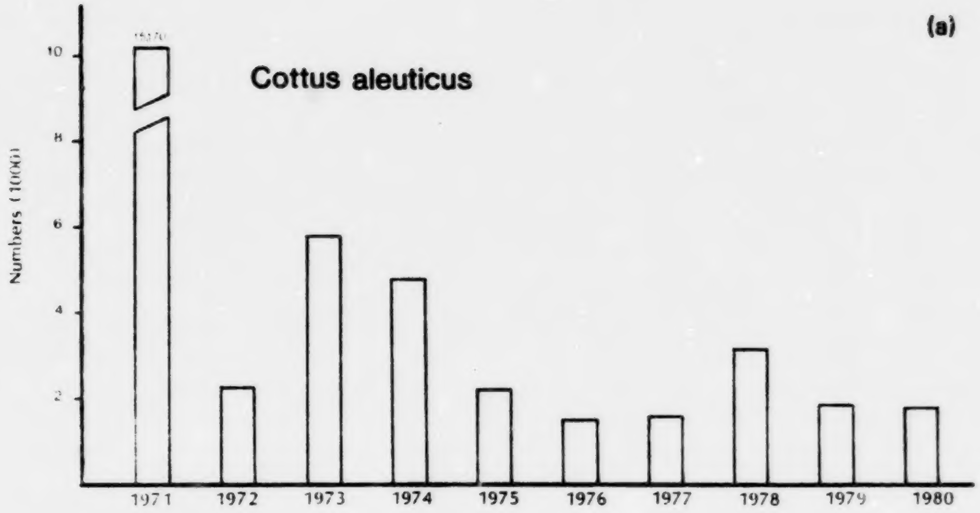


Fig. 6. *C. asper* late-summer (a) population estimates and (b) biomass estimates for lower Carnation Creek (0 m to 3070 m).



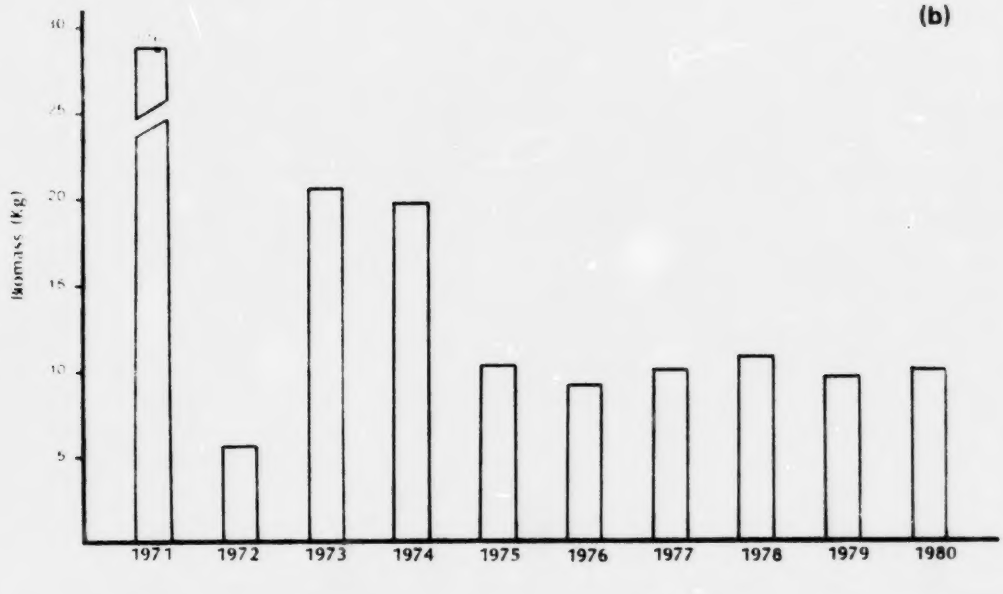


Fig. 7. *C. aleuticus* late-summer (a) population estimates and (b) biomass estimates for lower Carnation Creek (0 m to 3070 m).

Cottus aleuticus

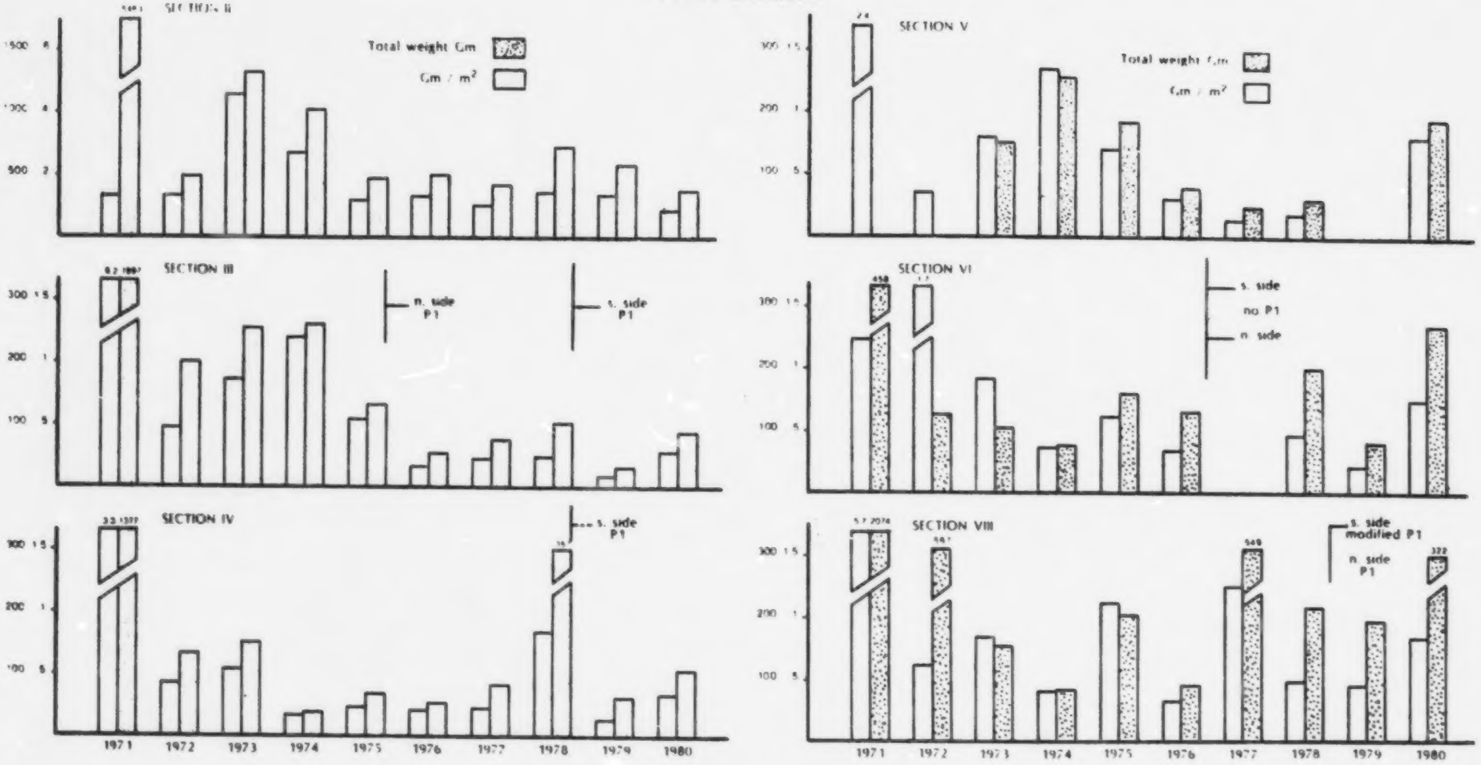


Fig. 8. Biomass estimates by study section, *C. aleuticus*, 1971 to 1982.

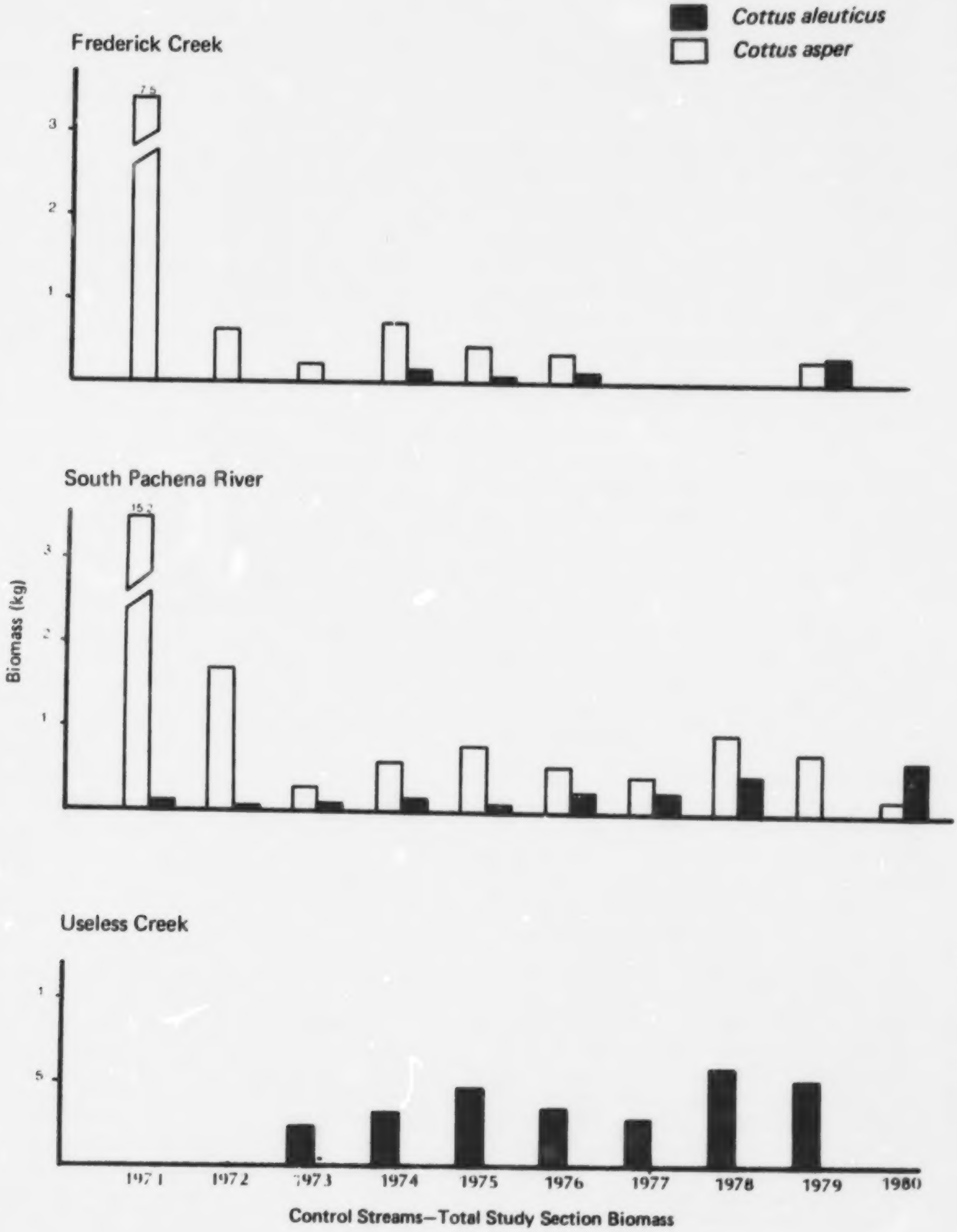


Fig. 9. Control streams; total study section biomass estimates.

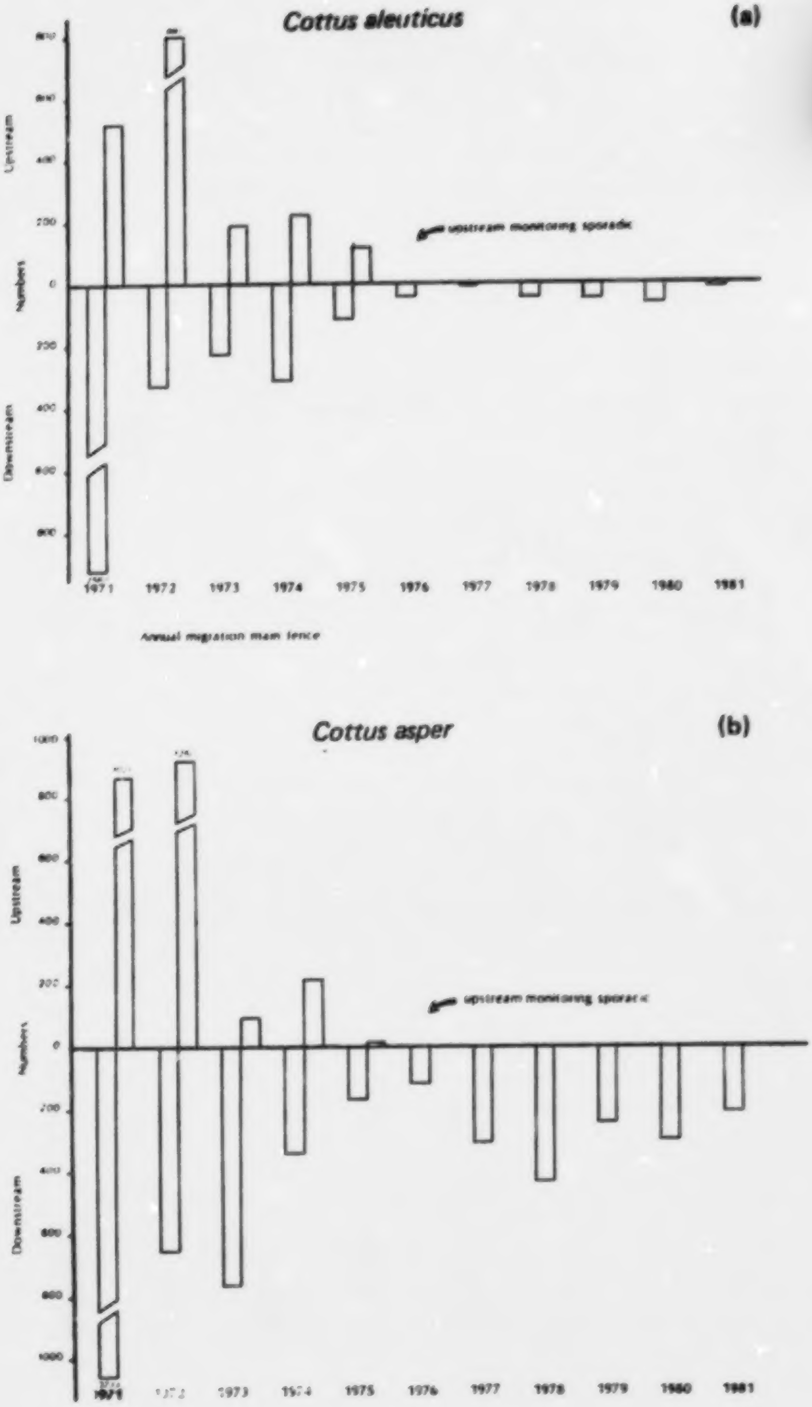


Fig. 10. Annual migration main fence: (a) *C. aleuticus* and (b) *C. asper*.

although influenced by sampling effort, also show a definite decline during this time. The migration data suggest either a change in sculpin behavior to avoid the traps or an actual decline in numbers.

From a comparison of stream population estimates and migration numbers, it is concluded that a major decline in population levels of both species did occur. The same trend (as evidenced by population estimates) in at least one control stream is also evident, suggesting one or more common factors at work. Sampling techniques (resulting in error in population estimates) and mortality are suggested as possible factors responsible for the decline.

The downward trend in populations of sculpins in all of the streams may partially be explained by sampling problems. However, in Carnation Creek, other data indicate that, in addition, an actual and substantial decline did take place.

In the spring of 1971, a broad-crested weir was constructed across Carnation Creek at approximately 450 m. This structure, installed to monitor watershed hydrology, created an in-stream barrier with a water level difference of approximately 45 cm. A fish ladder was installed to help reduce the barrier effect. Also in the spring of 1971, a temporary downstream main fish fence was constructed at approximately 200 m. This structure did not provide for upstream fish passage; however, it was replaced in the spring of 1972 with a permanent main fish-counting fence located at the upper limit of tidal influence. This fence was equipped with a small upstream fish ladder.

The decline in sculpin populations between 1971 and 1975 can currently be best explained by the presence of these in-stream barriers. Ringstad (1974) recorded large numbers of both species accumulating below the main fence between 1972 and 1974. Considering the temporal and spatial distribution of sculpins in Carnation Creek, this explanation seems reasonable. The resulting effect has been to severely restrict recruitment of sculpins to the stream habitat (0 m to 3070 m). However, depending upon the level of effort expended by field staff in assisting upstream movement over the barriers (i.e., seining, trapping, guidance of fish into mouth of fish ladder, etc.), recruitment could be highly variable from year to year, thus, contributing to variations in population estimates in upstream study sections. Although comparison of sculpin mean individual weight by study section, which may provide insight into changes in population structure throughout this calibration period, shows no trend, the small sample size combined with the pooling of all age groups in the samples have probably masked any real changes.

In summary, it is suggested that, although sampling technique and population estimate methodology has probably produced extra variability in the data on both the control streams and Carnation Creek, a substantial reduction of sculpins in Carnation Creek did occur. The significance of this phenomenon becomes important when the population estimates are subject to evaluation of the effects of logging prescriptions. Low recruitment is assumed to be a major factor regulating sculpin populations in Carnation Creek. It is likely that recruitment failure would mask the effects of any other influence whether man-caused or natural.

MacMillan and Bloedel (1979) and Dryburgh (these proceedings) have described the forest harvest operations. This last section of the paper considers possible effects of such operations on sculpins.

Between 1976 and 1980, the population level of *C. aleuticus* fluctuated between 1600 and 3000 individuals, with no obvious trend. The stream population of *C. asper* fluctuated between 90 and 300 individuals during this time, with a general upward trend to 1979 (Figs. 6 and 7).

Study sections V and VI were subjected to the most severe logging prescription. In these sections, logging in the winter of 1976-1977 took place to the stream edge—trees were felled into the stream and removed by conventional means. The biomass estimates of *C. aleuticus* (fish/m^2, gm/m^2, or total gm for study section) show no obvious change greater than that recorded in the control streams or other sections of Carnation Creek. A noticeable drop in *C. aleuticus* biomass is evident in Sections III to VI inclusive in 1979, which may have been the result of the fall 1978 freshet. This drop is not evident in the control streams. According to Schultz (1981), the stability of large organic debris in study sections subjected to the most intense logging treatment decreased substantially after logging. As previously discussed, stable large organic debris is probably an important determinant of sculpin habitat, and sculpin population levels may be influenced by its quantity and stability. Although a significant reduction in debris stability and quantity occurred in study sections subjected to intense logging treatment, no corresponding reduction in biomass of *C. aleuticus* was recorded.

Although the sampling system may have been too insensitive to reveal impact-related population changes and although other monitoring facilities may have altered sculpin movements and numbers, it is clear that their use of stream organisms for food and stable debris for cover make them vulnerable to stream condition changes. To the extent that managers may wish to maintain balanced fish faunas, consideration should be given to those environmental features that affect sculpins. Where it is demonstrated that high sculpin densities do impair commercial species production, the sculpin numbers may be modified by simple drop structures.

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THE EFFECTS OF LOGGING ON BENTHIC INVERTEBRATE STREAM DRIFT AND TROUT GROWTH RATES IN TWO SMALL WEST COAST VANCOUVER ISLAND STREAMS

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ABSTRACT

A study was conducted during the summer and fall of 1976 and 1977 on Carnation, Dick, and Ritherdon creeks and in the Barkley Sound area on the west coast of Vancouver Island to document the effects of logging on the density and behavior of drifting stream invertebrates and trout growth rates.

In the logged areas, daily light intensities reached a maximum of 1200 foot candles (fc), whereas in the unlogged areas, maximum light intensities were only 200 fc and generally less than 10 fc. At night, however, all light intensities dropped to less than 0.002 fc in all sample sites, regardless of whether or not they were logged. Duration of low light intensity usually lasted from one hour after sunset until approximately one hour before sunrise.

Although results were variable, no consistent differences in total drift densities and behavior of all drift invertebrates could be detected between pre- and postlogging and logged and unlogged samples on Ritherdon and Carnation creeks. Differences in drift behavior, as ascertained by recording temporal patterns of peak stream drift rates, were also not apparent between logged and unlogged stream sections. The latter was attributed mainly to low nighttime light intensities in all stream sections.

In the experimental situation, increasing (in late evening to midnight) light intensities from 0.002 to 0.009 fc failed to produce a response in drift behavior. Decreasing light intensities also failed to produce a response in drift rates of all species and was attributed to identical low nocturnal light intensities within treated and control sections.

Growth rates of rainbow trout fry were greatest in the logged areas and were attributed to higher temperatures in these areas compared to the unlogged sections. Increasing evening light intensities, in an attempt to make drift more available as a food source to trout, failed to show an effect on growth rates. It is likely that the use of large fish and little available drift accounted for this result. Decreasing overall light intensities also failed to show a response in trout growth rates. Trout fry grew equally well in both treated (illumination decreased) and control stream sections.

INTRODUCTION

The behavioral pattern of stream invertebrate drift, or diel drift, has been well documented by numerous authors (Bishop and Hynes 1969; Elliott 1967a, b; Hynes 1970; Muller 1954; Waters 1969, 1972). Although the precise mechanisms causing diel periodicity in stream drift are not well understood, it is generally accepted that a decrease in light intensity initiates an increase in drift rates of night active drifters (Holt and Waters 1967; Bishop 1969). The threshold light intensity level varies from about 1 to 5 lux (0.1 to 0.5 fc), measured at the water surface (Elliott 1967b; Holt and Waters 1967; Chaston 1969b). In some species, the threshold of light intensity is as low as 0.001 lux (Bishop 1969).

Both terrestrial and aquatic invertebrate stream drift are utilized by trout to varying degrees, depending largely on which is more available (Reed and Bear 1966; Chaston 1969a; Jenkins, Feldmeth, and Elliott 1970; Griffith 1974). Although peak feeding activity is often correlated with high drift rates (Elliott 1967a; Jenkins, Feldmeth, and Elliott 1970), food consumption generally tends to be opportunistic, with all available food items including insect exuviae being utilized in times of scarcity (Mundie 1974). Experimental evidence indicates a decrease in utilization of both the terrestrial and benthic components of drift with decreasing light intensities. Few animals are taken at night, relative to the total number drifting, than during the day (Jenkins 1969). Additional studies by Tanaka (1970) indicate a cessation of feeding on sedimented foods at light intensities below 0.030 to 0.035 lux (0.003 to 0.0035 fc).

Because of these interrelated factors, the present study attempts to measure the effects that light intensity changes, resulting from clear-cut logging, have on the diel pattern of stream invertebrate drift and how these changes, if significant, affect the food supply of juvenile salmonids.

METHODS

Invertebrate drift samples were collected every hour over a 24-hour period in two 200 micron mesh green nitex nets (15 cm x 25 cm opening) and preserved in 10% formalin. Current velocity was measured between and just upstream of the nets by a rotary current velocity meter. Light intensity measurements were made with an IL (International Light) 600 Research Photometer and an IL660 Photo Multiplier power supply. Sample runs (a 24-hour series of samples) were collected in both logged and unlogged sites, as well as in before and after logged areas of Ritherdon and Carnation creeks during the fall of 1976 and 1977.

Similar data collections were made in 4 experimental stream troughs (2 control, 2 treated) located on Dick Creek, a tributary to Carnation Creek. Individual troughs contained 2 pools and 2 riffles of equal area (0.61 m x 2.44 m each). In the first experiment, illumination was increased in the treated troughs during the 20- to 24-hour period, whereas in the second, it was decreased throughout the day. Although only a single sample run was collected for each experiment, treatment continued daily for over a month.

Field trout growth studies took place in Carnation and Ritherdon creeks. Rainbow trout fry (*Salmo gairdnerii* Richardson) were obtained by electrofishing from the south fork of the Sarita River near Bamfield. Their lengths were measured and they were placed in enclosures in the stream.

Each enclosure was constructed out of plywood, hemlock boards, and 0.7 cm mesh metal screening. The dimensions of the box or enclosure were 91.4 cm x 30.5 cm x 10.2 cm. A baffle, as cover for the trout, was contained in the enclosure, as well as a removable screen for cleaning. The front, top, and back of the enclosure were screened; the bottom and sides were wooden. A top cover, also wooden, was nailed into place to prevent escape of trout fry.

The enclosures were placed in the stream downstream of a riffle section and secured to the stream bottom by boulders and to the streamside by ropes. One fry was placed in each box. In both creeks, five enclosures were placed in a logged section and five in an unlogged section.

Boxes were placed in such a fashion as to ensure adequate distance between them. This last detail is important in order to minimize the effect of one enclosure (fish predator or drift removal) on the others further downstream. Generally, a distance of approximately 50 m was considered sufficient for this purpose.

Enclosures were placed in all 20 sites on August 4, 1977, and removed September 10, 1977. Lengths were measured before and after. Corresponding weights were calculated by: wt (g) = $1.13 \times 10^{-5} L^3$; where L = fork length in millimetres (Narver and Anderson 1974). Weights were calculated, since mortality of the small fry due to excessive handling was likely.

Two sets of experimental trout growth studies, again on rainbow trout, were conducted during the summer and fall of 1977. Both were carried out in the experimental stream troughs on Dick Creek.

The first involved placing trout in each of the four extreme downstream pools in each experimental stream section and increasing evening light intensities in a pair of the troughs, as was done with the drift experiments discussed previously. Fish were placed in the pools July 16, 1977, and removed August 23, 1977. Both length and weight were obtained for each fish before and after the experiment. All pools were completely surrounded by 0.7 mm mesh plastic netting to prevent the trout from jumping out of the original pools in which they were placed.

The second experiment was identical in design to the first, but instead of illuminating the pair of experimental troughs, they were darkened with strips of black plastic. Smaller fish were used in this experiment than in the former, and for this reason, the weights were again calculated. Four fish were placed in each pool on September 10, 1977, and removed November 8, 1977.

Overall differences between field-collected drift samples (n/m^3) were ascertained by paired sample t-tests. The unifying variable of the paired samples was time of day. The time "peak" drift rates, occurred in the sample run relative to sunrise or sunset, was used to determine effect of logging on drift behavior. If the time of peak drift rates was shifted relative to sunrise or sunset (determined visually from graphs) in either logged or unlogged sites and if the shift was consistent, a difference was assumed. Thus, in the field samples, two things were tested. These were: (1) overall numerical differences between the pairs in the sample run, i.e., did one sample run have a greater or lesser number of individuals than another; and (2) were behavioral differences, in terms of the timing of the diel drift rates relative to sunrise and sunset, apparent? This analysis was also employed in determining differences between experimentally treated and control sections. If the tests indicated no significant differences between compared sample runs, no difference between the sample runs was assumed.

Since extremely large and obvious differences were apparent in daytime light intensities between logged and unlogged sites, paired t-tests were carried out only on those paired samples after sunset and before sunrise.

All light intensity and n/m^3 of animals were plotted by time.

Fish weights (before and after) were graphed and significant differences determined by analysis of variance. If a significant difference in lengths and/or weights of rainbow trout fry between logged and unlogged sites was determined, then this difference was attributed to the site being logged or unlogged.

RESULTS

Although large daytime increases in light intensities were documented in the logged sites of both Ritherdon and Carnation creeks (Fig. 1), nighttime intensities were similar regardless of site location (Table 1). Light intensities during the night at all sites were well below the threshold intensities for drift to increase and trout to stop feeding. Canopy removal appears to affect primarily daytime stream illumination, whereas nocturnal intensities are unchanged.

Consistent behavioral differences in the drift between pre- and postlogging and logged and unlogged sites were not readily apparent from the data (Fig. 2). Curves were, in fact, surprisingly similar, especially in the pre- and postlogging sample runs collected at C-weir in Carnation Creek. Slightly higher drift densities were encountered in the logged versus unlogged sample runs ($\bar{D}$ = +, Table 2) in both Carnation and Ritherdon creeks.

In the experimental situation, increasing evening (Dick Creek, September 11) and decreasing daytime (Dick Creek, October 17) light intensities (Fig. 3) failed to produce any response in drift behavior (Fig. 4). Both curves within each experimental set were similar. Slightly more animals were captured in the control troughs of the second experiment (Dick Creek, October 17). This may be the result of both low numbers drifting (high variability) and slightly more water and, therefore, more invertebrate drifters passing through the control troughs.

A significant ($p = 0.0000$) overall difference in average weight gain from the date trout were placed in boxes (0.538 g on August 4, 1977) to the date they were removed (1.090 g on September 10, 1977) was observed regardless of whether these were in logged or unlogged areas on Carnation or Ritherdon creeks. That is, all trout gained weight significantly, regardless of location. A further significant ($p = 0.0009$) difference in trout fry weight gain was observed between creeks, regardless of whether the site was logged or unlogged (Table 3). Trout in Ritherdon Creek gained slightly more weight (avg. wt. gained = 0.681 g) than did trout in Carnation Creek (avg. wt. gained = 0.421 g). The most outstanding results, however, were the large weight increases attained in the logged versus the unlogged sections in both creeks (Fig. 5). In Ritherdon Creek, this weight gain in the logged area amounted to 1.276 g, but in the unlogged section, only 0.078 g. In Carnation Creek, average weight gained was 0.682 g in the logged and 0.161 g in the unlogged sections respectively. The most dramatic weight gain, then, occurred in the logged section of Ritherdon Creek.

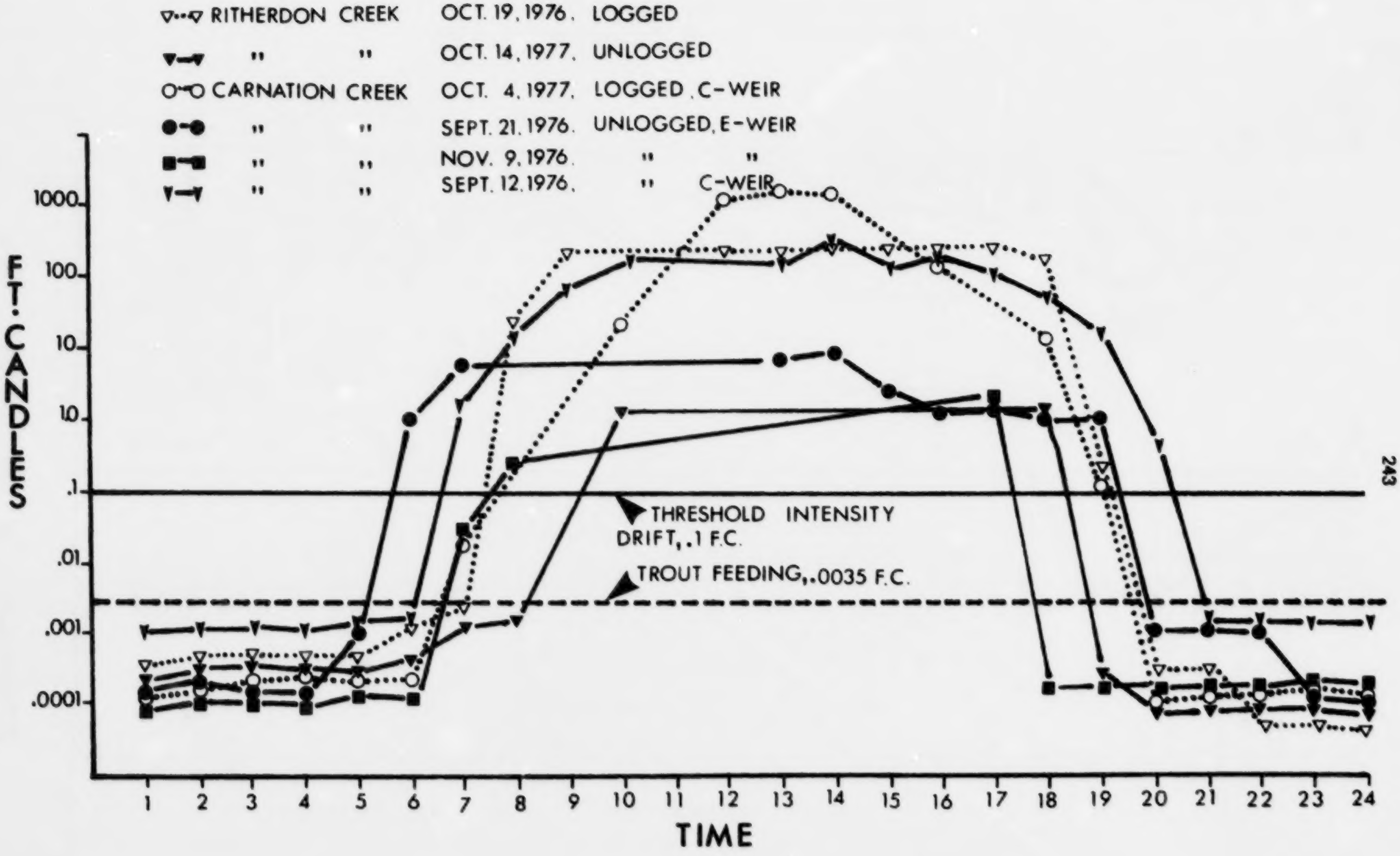

Fig. 1. Light intensity changes during 24-hour periods in logged and unlogged sections of Carnation and Ritherdon creeks.

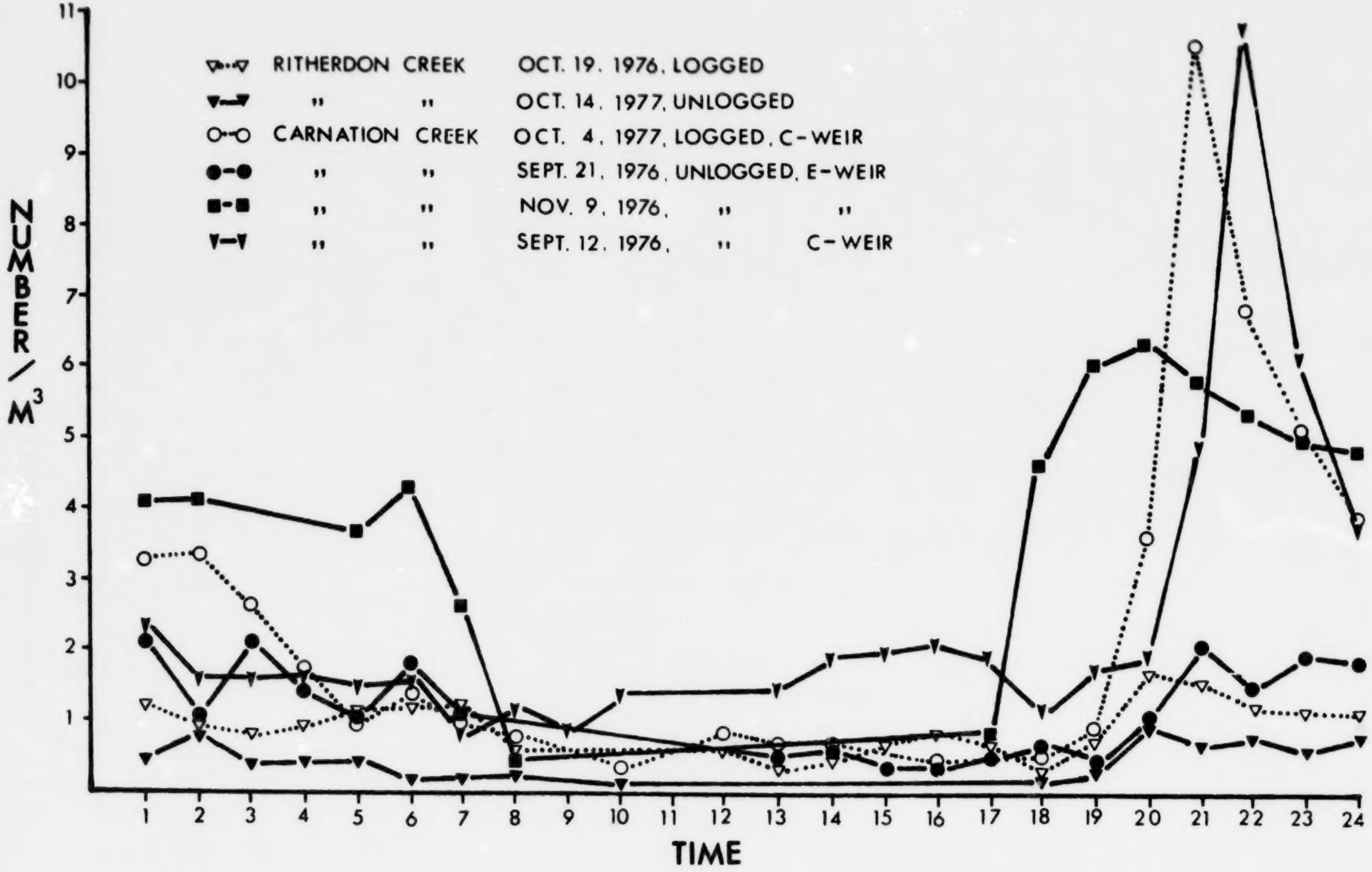

Fig. 2. Drift density changes during 24-hour periods in logged and unlogged sections of Carnation and Ritherdon creeks.

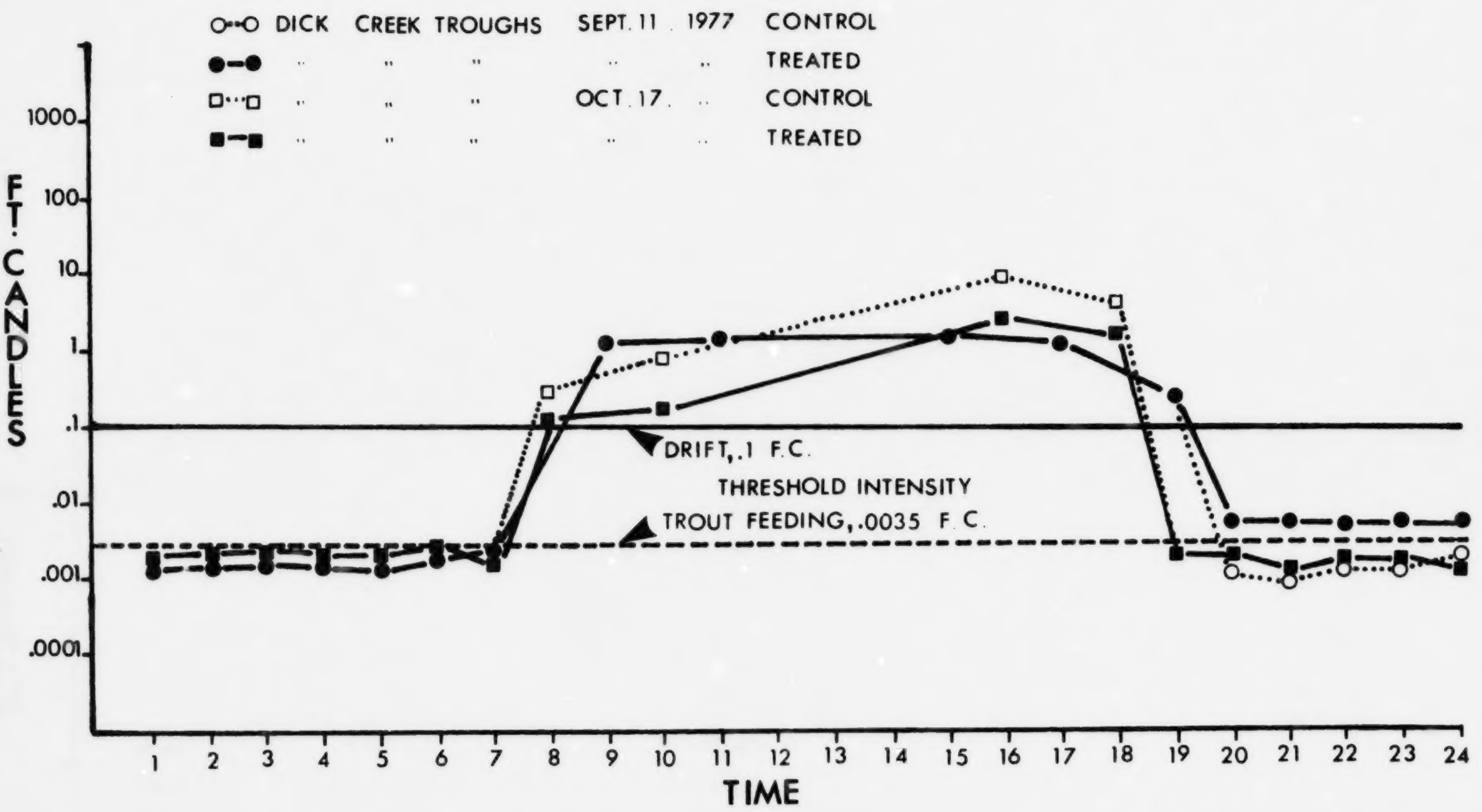

Fig. 3. Light intensity changes in treated and control experimental stream troughs of Dick Creek.
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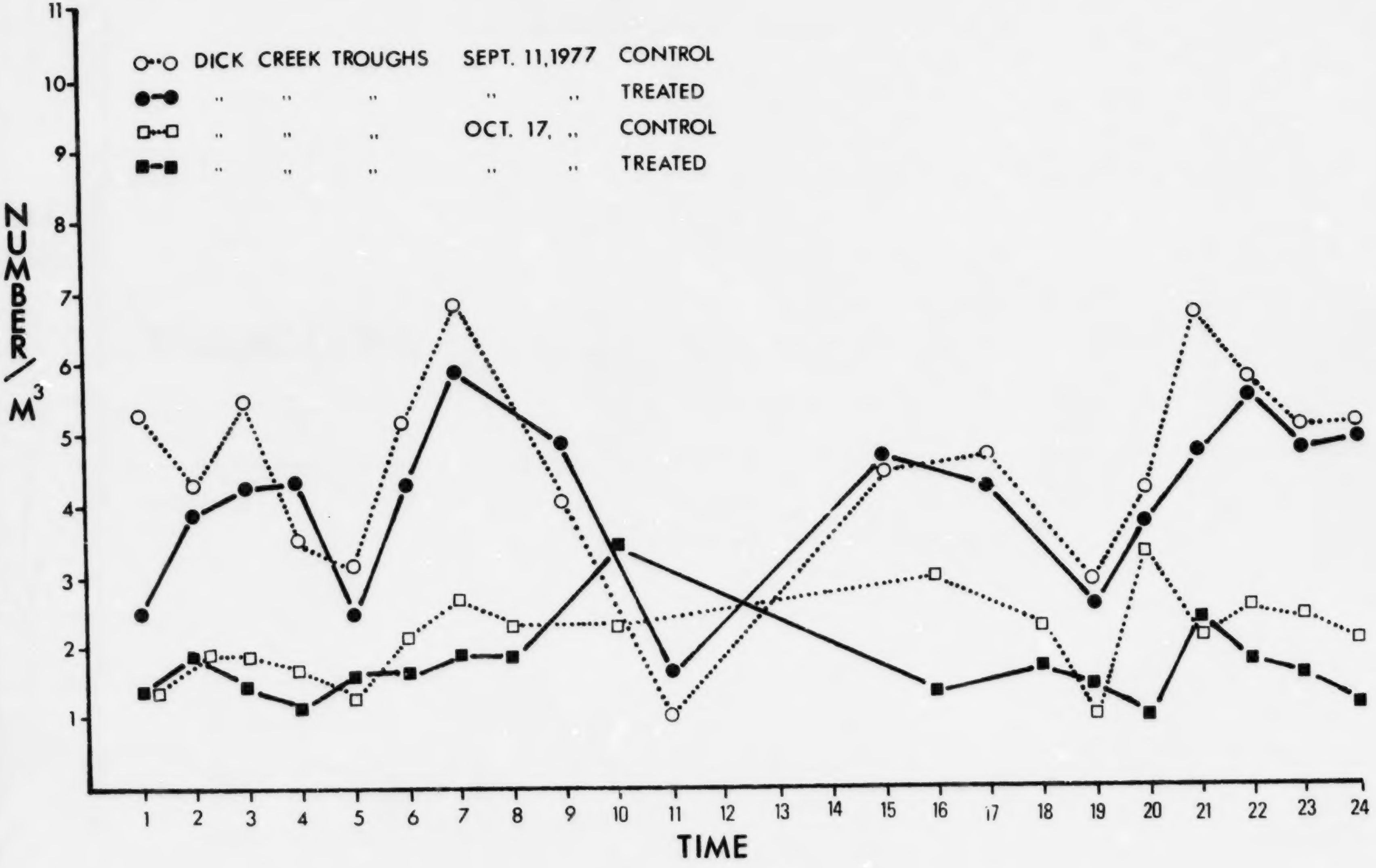

Fig. 4. Drift density changes in treated and control experimental stream troughs of Dick Creek.

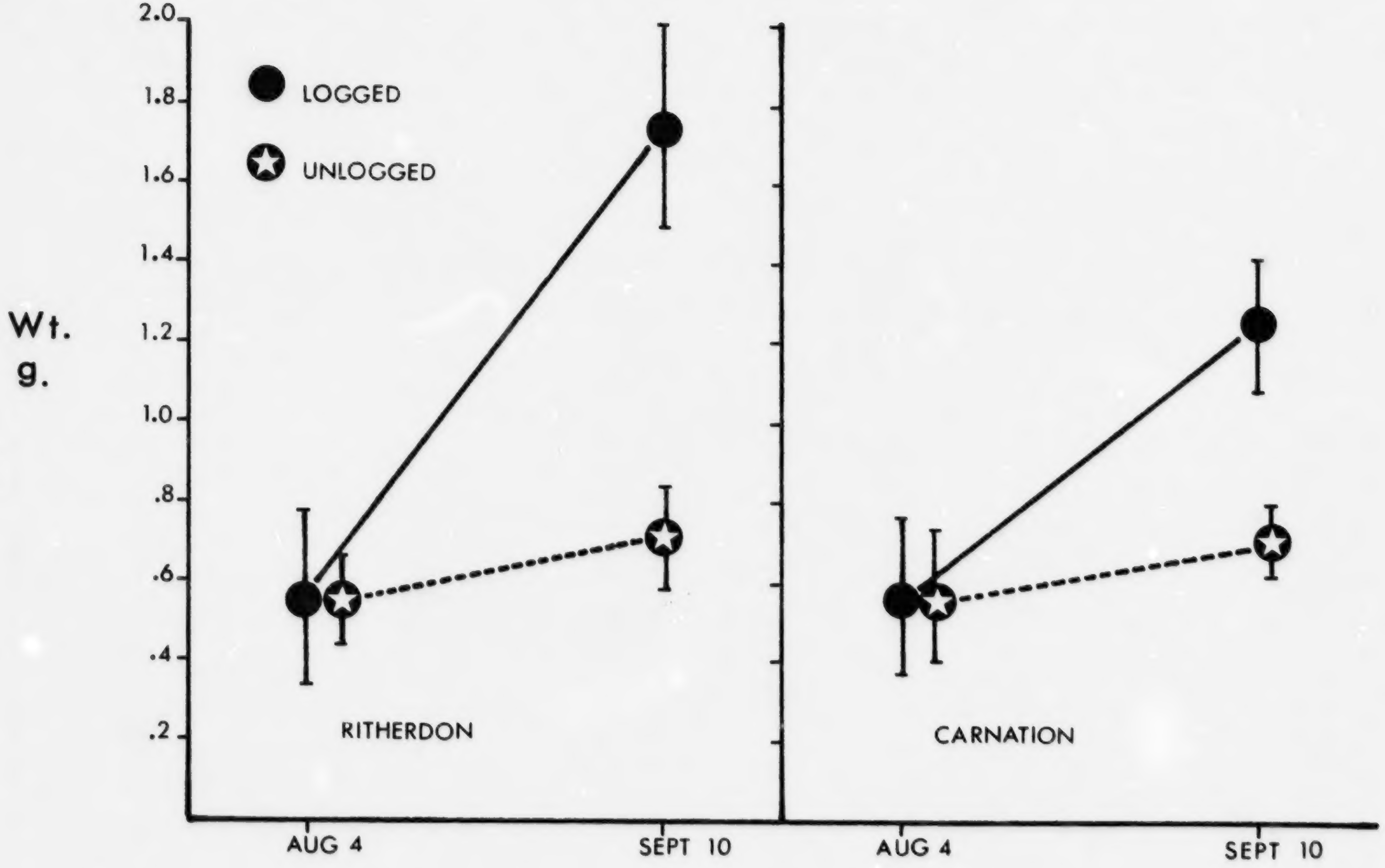

Fig. 5. Weight increases in rainbow trout fry from August 4 to September 10 in logged and unlogged sections of Ritherdon and Carnation creeks.

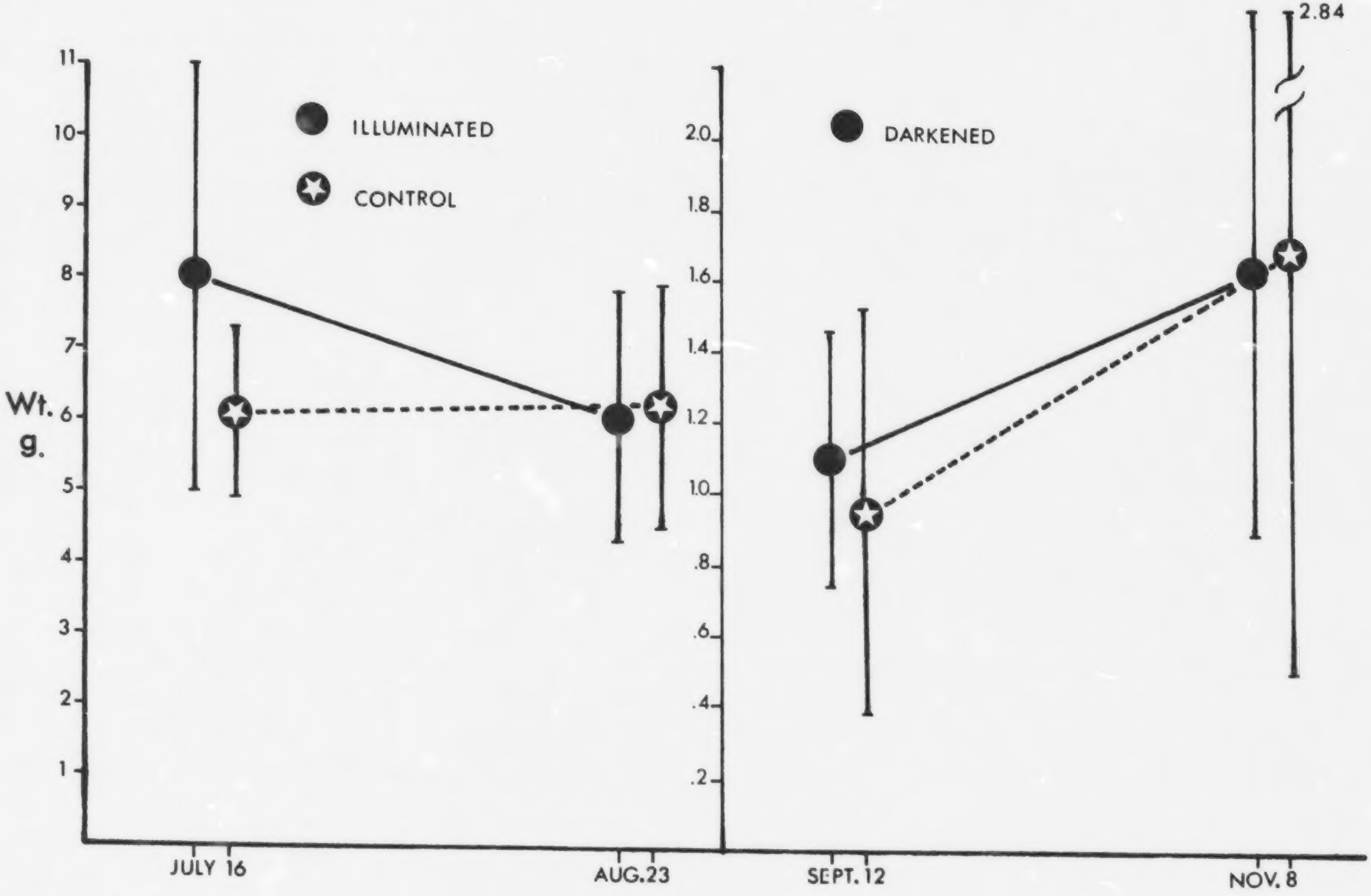

Fig. 6. Weight changes in rainbow trout juveniles in the experimental stream troughs of Dick Creek.

Table 1. Paired t-test results of light intensity measurements (foot candles) in the Carnation, Ritherdon, and Dick creeks.

	$\overline{X}$	Y	$\overline{D}$	$S_{\overline{D}}$	df	t	P
X = Prelogging, September 12, 1976, near C-weir Y = Postlogging, October 4, 1977, near C-weir	.002	.0005	.0015	.0001	8	15.931	< .05
X = Logged, near C-weir, October 4, 1977 Y = Unlogged, near E-weir, September 21, 1976	.0005	.0008	–0.0003	.0002	9	–1.749	> .05
X = Unlogged, September 21, 1976, near E-weir Y = Unlogged, November 9, 1976, near E-weir	.0009	.0004	.0004	.0002	7	3.353	< .05
X = Logged, October 19, 1976, Ritherdon Creek Y = Unlogged, October 14, 1977, Ritherdon Creek	.0004	.0005	–0.0001	.0001	10	–1.569	> .05
X = Treated, illumination increased Y = Control	.4227	.4202	.0025	.0009	16	2.610	< .05
X = Treated, illumination decreased Y = Control	.3253	.6940	–0.3687	.3115	16	1.184	> .05

Table 2. Paired t-test results of drift density measurements (n/m^3) in the Carnation, Ritherdon, and Dick creeks.

	$\overline{X}$	Y	$\overline{D}$	$S_{\overline{D}}$	df	t	P
X = Prelogging, September 12, 1976, near C-weir Y = Postlogging, October 4, 1977, near C-weir	2.7236	2.6723*	.0513	.4709	17	.109	$> .05$
X = Logged, near C-weir, October 4, 1977 Y = Unlogged, near E-weir, September 21, 1976	2.8124*	.1107*	2.7017	.6573	16	4.110	$< .05$
X = Unlogged, September 21, 1976, near E-weir Y = Unlogged, November 9, 1976, near E-weir	1.3161*	4.4864	−3.1714	.4007	12	−7.914	$< .05$
X = Logged, October 19, 1976, Ritherdon Creek Y = Unlogged, October 14, 1977, Ritherdon Creek	1.0098	.5122	.4976	.0769	14	5.89	$< .05$
X = Treated, illumination increased Y = Control	4.1286	4.5705	−0.4419	.2221	16	−1.989	$> .05$
X = Treated, illumination decreased Y = Control	1.7144	2.2042	−0.4898	.1883	16	−2.602	$< .05$

* differences in averages of identical sample runs are due to differential pairing in t-tests.

Table 3. Trout growth studies, analysis of variance results.

Source	DF	SS	MS	F	P
Field Trout Growth Studies					
Before and after	1	3.04	3.04	294.330	0.0000
Before and after, between creeks	1	0.17	0.17	16.373	0.0009
Before and after, logged and unlogged	1	1.83	1.83	176.707	0.0000
Experimental Trout Growth Studies					
Treated = illumination increased					
Before and after	1	2.693	2.693	0.697	0.415
Treated and control	1	7.742	7.742	2.005	0.175
Treated = illumination decreased					
Before and after	1	3.018	3.018	4.989	0.035
Treated and control	1	0.026	0.026	0.043	0.837

In the first experiment, no overall significant difference ($p = 0.415$) could be detected in trout weight gained in both treated (illuminated) and control stream troughs between the dates fish were placed and removed (Table 3, Fig. 6). In the treated section, an average weight loss was, in fact, observed. There was no significant difference between treated and control sections with respect to trout weight. All fish, therefore, were on average no different from one another, regardless of location (treated versus nontreated) and time (before and after). This overall lack of significance with respect to weight gain is most likely due to the large sizes of rainbow trout juveniles used (about 7.00 g). Insufficient trout food (drift) was present in the troughs to feed the trout adequately, and therefore, no differences were detectable.

In the second experiment, where the treatment effect consisted of decreasing light intensities, a significant difference ($p = 0.035$) between before and after weight values was obtained in fish in both treated as well as control sections. No significant difference ($p = 0.175$) could be attributed to the treatment effect; trout grew equally well in all stream troughs. The crossing of the treated and control lines in Figure 6 is not a significant interaction effect (increased growth in control) but is more likely due to the randomness of the values.

Although not included in this study, continuous stream temperature records were kept on Carnation Creek at E-weir. Maximum and associated minimum monthly recorded temperatures at E-weir for the summer of 1976 were 13.1° and 10.2°C respectively in August. In 1977, these were 14.8° and 10.7°C respectively, also in August. Far higher temperatures were recorded at 1600 m on the stream during the summer of 1977 (postlogging) than the summer of 1976 (prelogging). In the former, maximum and minimum recorded temperatures during August were 16.5° and 11.4°C respectively, whereas in the latter, they were 12.0° and 9.4°C respectively. Stream temperatures were, therefore, very different between sites in the logged and unlogged areas during the trout growth studies.

Stream temperatures in Dick Creek experimental stream troughs were identical in all sections. Temperature records were not taken for Ritherdon Creek.

DISCUSSION

Field Drift Studies

Dramatic increases in direct solar radiation to the stream resulting from clear-cut logging were observed in both Carnation and Ritherdon creeks. In Carnation Creek, light intensity during the day increased from a maximum of 219 to 1208 fc in pre- and postlogging sample runs respectively. In Ritherdon Creek, light intensity in the logged area was in excess of 231 fc, whereas in the unlogged area, it only reached 3.4 fc. Maximum illumination was not reached during sample runs since about 10 000 fc can be attained with the sun at the zenith on a horizontal surface (Reifsnyder and Lull 1965). The daily light increases observed on these systems due to canopy removal are not unusual. Studies elsewhere have shown that incident solar radiation under forest canopies is often less than 10% of what is in clearcuts (Vesina and Peck 1964). Such changes in daytime light intensities are reflected in stream temperatures (Brown 1970, 1971; Brown and Krygier 1967, 1970) where increases are usually observed. The maximum temperature in Carnation Creek in the postlogging sample was 16.5°C, whereas prior to logging, it was 12.0°C. Increased stream temperatures, however, do not appreciably alter the behavior of benthic invertebrates (Wojtalik and Waters 1970) but, in association with additional light availability, can increase the primary production rates (Phinney and McIntyre 1965; Warren 1960). Maximum drift rates in Carnation Creek observed in the 1976 prelogging sample run were associated with lower temperatures than in the postlogging sample run, where higher temperatures were associated with lower drift rates. Further upstream, near E-weir, in two sample runs collected on September 21 and November 9, lower drift densities of the former were collected in higher temperatures than the latter.

The large changes in daytime light intensities in Carnation and Ritherdon creeks were not apparent during the night. During this time, shortly after sunset, in both logged and unlogged situations in these two creeks, light intensities dropped to similarly low levels—generally less than 0.001 fc. In Ritherdon Creek, these light intensities ranged from 0.001 to 0.0002 fc in both logged and unlogged sites. Similarly in Carnation Creek, the range was from 0.0025 to 0.0002 fc in pre- and postlogging sample runs. The duration of this low light intensity extended from about one hour after sunset to one hour before sunrise. Such overall low nightime light intensities are, therefore, not likely to have an effect on altering the drift behavior of benthic invertebrates. Light intensities at the stream surface of between 0.001 and 0.0001 fc were determined to be the threshold level, above which drift would decrease and below which it would increase (Bishop 1969). Although significant nighttime differences in light intensities were recorded between logged and unlogged sites, these differences were tested between values which were all still well within the levels where drift is expected to occur. The similarity of low nighttime light intensity between logged and unlogged sites was reflected in the similar behavior of benthic invertebrate drift in all sample runs.

In Carnation Creek, the pre- and postlogging sample runs indicated identical diurnal drift patterns, in both overall behavior and numbers. Low daytime total drift densities were higher in the prelogging (1.0/m^3) than in the postlogging (0.5/m^3) sample runs. Nighttime peaks of about 11/m^3 were similar in both sample runs. The large difference in light intensity observed during the day caused by removal of the streamside forest canopy, therefore, had little immediate effect on altering total drift rates.

In Ritherdon Creek, where sampling took place six years after forest removal, only slight differences in total densities and diurnal pattern of the drift between logged and unlogged sample run sites were observed. Here, maximum drift intensities in both sites occurred at the same time—three hours after sunset. In the logged sample run, however, the maximum drift rate was 1.68 invertebrates/m^3, whereas in the unlogged, it was 0.84. Seasonal changes in drift densities in sample runs collected near E-weir on Carnation Creek showed greater fluctuations than those just described on Ritherdon Creek. On September 21, the overall average total drift density near E-weir on Carnation Creek was 1.316/m^3. Overall drift intensities at the same location, but collected on November 9 and averaged over identical times, had increased to 4.4864/m^3.

The implication here is that within unlogged sites, fluctuations in drift density due to natural circumstances are large—large enough, in fact, to encompass the differences observed between logged and unlogged situations.

The drift pattern appears to be controlled more by sunset and low light intensities than by increased daytime luminosity. Logging on a strictly light intensity basis, therefore, had little effect on the behavior of stream drift. The greatest degree of difference was observed in the drift densities of insect groups and individual species (de Leeuw 1981). The degree of change was greatest in Carnation Creek where large differences, particularly increases in depterans and decreases in ephemeropterans, were noted between pre- and postlogging sample runs. Although these differences were also observed in Ritherdon Creek, they were less apparent.

Species diversity changes in the drift were observable, with fewer species occurring primarily in the logged sections. In Carnation Creek, species diversity in the drift declined from 30 to 23 in pre- and postlogging sample runs respectively. The greatest decline occurred in the Trichoptera, but no change was observed in the Diptera. In Ritherdon Creek, species diversity in the unlogged section was 28, while in the logged, it was 21. In this case, also the greatest degree of difference was attributable to the trichopterans. The dipteran species were again least affected (de Leeuw 1981).

Decreases in benthic insect numbers and species diversity have been recorded in association with increases in sedimentation (Gammon 1970), often associated with logging and especially skidding and road construction (Slaney, Halsey, and Smith 1977). When invertebrate drift rates were compared on two forks of Caspar Creek in California, road construction resulting in siltation of streambeds was found to be immediately detrimental to most aquatic invertebrates and conditions favored dipterans and plecopterans (Burns 1972; Brode, Burns, and Smith 1973). Increases in these latter groups, in fact, compensated for losses in the other groups such as ephemeropterans. The latter group was found to be most sensitive to siltation.

In Carnation Creek, a dramatic increase of the dipterans, primarily the Chironomidae, in the postlogging situation was apparent and accounted for over half of the total drift density in this sample run (de Leeuw 1981). In the prelogging situation, this species was a minor contributor to the total drift density. Drift behavior or patterns of the Chironomidae were unaltered in pre- and postlogging sample runs. In the same stream, a decline of 50% in the Ephemeroptera occurred from pre- to postlogging sample runs and was due primarily to a decrease in drift density of two species of Baetidae. Similar changes were observed in Ritherdon Creek. Overall drift behavior and densities, then, are not appreciably different in logged and unlogged and pre- and postlogging sites. The major change occurs in dominance of individual species and species diversity. The results of this study corroborate those of previous investigations with regard to overall drift density. Drift behavior was not investigated by those earlier studies.

Experimental Drift Studies

In the first set of experiments, light intensities were significiantly increased to 0.0090 fc within the treated section of the stream troughs during treatment time, from 20:00 to 24:00 hours. Control section illumination was 0.001 fc. Other than during treatment time, light intensities were identical in both treated and control sections. Maximum light intensities during the drift study period (September 11) were very low—1.8 fc. Overall total drift intensities did not respond to this light increase since similar drift intensities and patterns occurred in both treated and control sections.

In the second experiment, nighttime light intensities of treated and control sections were identical and ranged from 0.0042 to 0.0016 fc. During the day, light intensities were 2.77 and 8.09 fc in treated (darkened) and control sections respectively. Of interest here is the fact that, even though elaborate steps were taken to shade or darken the treated stream section, no difference in nighttime light intensities between this and the control were apparent. In this last experiment, other than all groups combined, the overall drift pattern and density of individual groups and species were similar in both treated and control sections. Although increases were observed during the daytime hours in the totals of all groups combined, the peak in the treated section occurred at 10:00 hours and in the control at 20:00 hours. Species diversity in both sections, again, was identical.

The overall treatment effect of changing light intensities on the drift as a whole, therefore, was minimal in both experiments. The daytime light intensities in the second experiment (darkened) were higher in both treated and control sections (2.77 and 8.09 fc respectively) than in the first (illumination increased at night), where in both sections identical daytime measurements of 1.8 fc were observed. It was in the former, however, that the greatest increases in daytime invertebrate activity took place. In both cases, the major contributors to the drift were the ephemeropterans and the dipterans. With the Ephemeroptera, a noticeable shift in peak drift intensity was evident between the September 11 (high intensity increased) and the October 17 (darkened) experiments (de Leeuw 1981). In the former, it occurred at 07:00 hours, in the latter at 21:00 hours. No difference between treated and control sections in either of these two studies, however, was noted.

Field Trout Growth Studies

It is unlikely increased growth rates in the logged areas, as compared to the unlogged sites, can be explained solely on the basis of food. Behavior and density of the drift in Carnation and Ritherdon creeks were not very different (as outlined previously) between logged and unlogged sample runs. It is possible that higher drift densities occurred during the time trout were in the creeks than during drift sample time. In four reaches of Rosanne Creek in central British Columbia, all components of the drift reached peak densities in the summer months (Slaney, Halsey, and Smith 1977). It is likely such increases would occur in Carnation and Ritherdon creeks in both logged and unlogged sites. This leaves the situation of increased growth rates in the clearcuts still unexplained.

In Carnation Creek, average weight gain per fry in the logged area was 0.682 g, while in the unlogged, it was 0.161 g. In Ritherdon Creek, overall weight gain per fish was slightly greater, with 1.276 g per fry gained in the logged as compared to 0.078 g in the unlogged area. Comparatively high temperatures during the trout growth study periods in the logged areas, resulting from increased exposure of the stream to direct solar radiation, are likely responsible for the relatively high growth rates here. In Oregon, annual maximum stream temperatures increased by as much as 7.8°C following clear-cut logging (Brown and Krygier 1970). In central British Columbia, trout populations benefitted in growth rates from moderate increases in water temperature in logged areas (Slaney, Halsey, and Smith 1977).

Experimental Trout Growth Studies

It was not possible to determine the effect of treatment (light increases to 0.0090 fc from 20:00 to 24:00 hours) in the first trout growth experiment (July 16 to August 23), since no difference was established between treated and control sections. It is likely that, due to the large size of trout used, growth of all individual fish was minimal, since no difference in weights between fish prior to and after the growth period was evident in both treated and control sections. An increase in the treated section was expected, since trout were able to feed on the drift due to greater light availability. Drift did occur during this time.

In the second experiment, decreasing light intensities did not affect growth of fry. Increases in weight were parallel in both treated and control sections. Temperatures and nighttime light intensities were identical in both sections. Daytime light intensities were different, with a decrease occurring in the treated section. The length of time fish could feed was similar in both sections, and since equal quantities of food were available in both troughs, all trout grew equally well. Feeding rainbow trout evidently need illumination of at least 0.003 fc to be able to see their prey (Tanaka 1970). In the majority of sample runs in this study, both field and experimental, feeding of trout at night on peak drift rates is not possible due to low light intensities.

SUMMARY

1. A large increase in daytime light intensities observed in Carnation and Ritherdon creeks resulting from forest canopy removal did not result in a similar increase at night. During this time, luminosity usually dropped to less than 0.002 fc shortly after sunset and continued until about one hour before sunrise.

2. The overall behavior and density of the drift was not appreciably different between logged and unlogged and pre- and postlogging sample runs on these two creeks. The lack of difference in the behavioral pattern of the drift between logged and unlogged and pre- and postlogging sample runs was attributed to similar low nighttime light intensities in all sample runs.

3. A decline in benthic invertebrate species diversity from unlogged to logged and pre- to postlogging sample runs was evident in both Carnation and Ritherdon creeks. In Carnation Creek, the Ephemeroptera was the dominant group in the prelogging and nonlogging sample runs. The Diptera, primarily Chironomidae, was the dominant group in the postlogging sample run on this creek (de Leeuw 1981).

4. In the experimental situation, evening to midnight light intensities increasing to 0.0095 fc produced a decreasing drift effect in the Ephemeroptera, primarily the Baetidae. This decline was masked by increases in dipteran drift, mainly Chironomidae (de Leeuw 1981).

5. Light intensities, decreased by shading in the experimental situation, failed to produce a drift

response which was significantly different from the unshaded section. Nighttime light intensities in both 4 and 5 were similar to both treated and control sections.

6. Trout growth was greatest in the logged sections in Ritherdon and Carnation creeks and was attributable primarily to a substantial increase in stream temperature in these more exposed reaches. Growth in unlogged sections was minimal.

7. Trout growth in stream sections where evening light intensities were increased or where they were decreased throughout the day did not differ from that in untreated sections.

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LOGGING IMPACTS AND SOME MECHANISMS WHICH DETERMINE THE SIZE OF SPRING AND SUMMER POPULATIONS OF COHO SALMON FRY IN CARNATION CREEK

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INTRODUCTION

An understanding of the impacts of forest practices on salmonid resources is a primary concern of western North American resource managers. Sound resource decision making requires a thorough understanding of how these resources are integrated in watershed ecosystems.

A 15-year study was initiated in 1970 to examine the effects of logging on a small west coast watershed. Emphasis was placed on understanding watershed processes, as upslope and streamside activities can produce both negative and positive in-stream effects (Narver 1972; Cederholm et al. 1981).

This paper describes the patterns of emergence, seaward movement, distribution, densities, size, and growth of coho fry during spring and summer. Attempts are made to identify and explain the causal elements which affected the population.

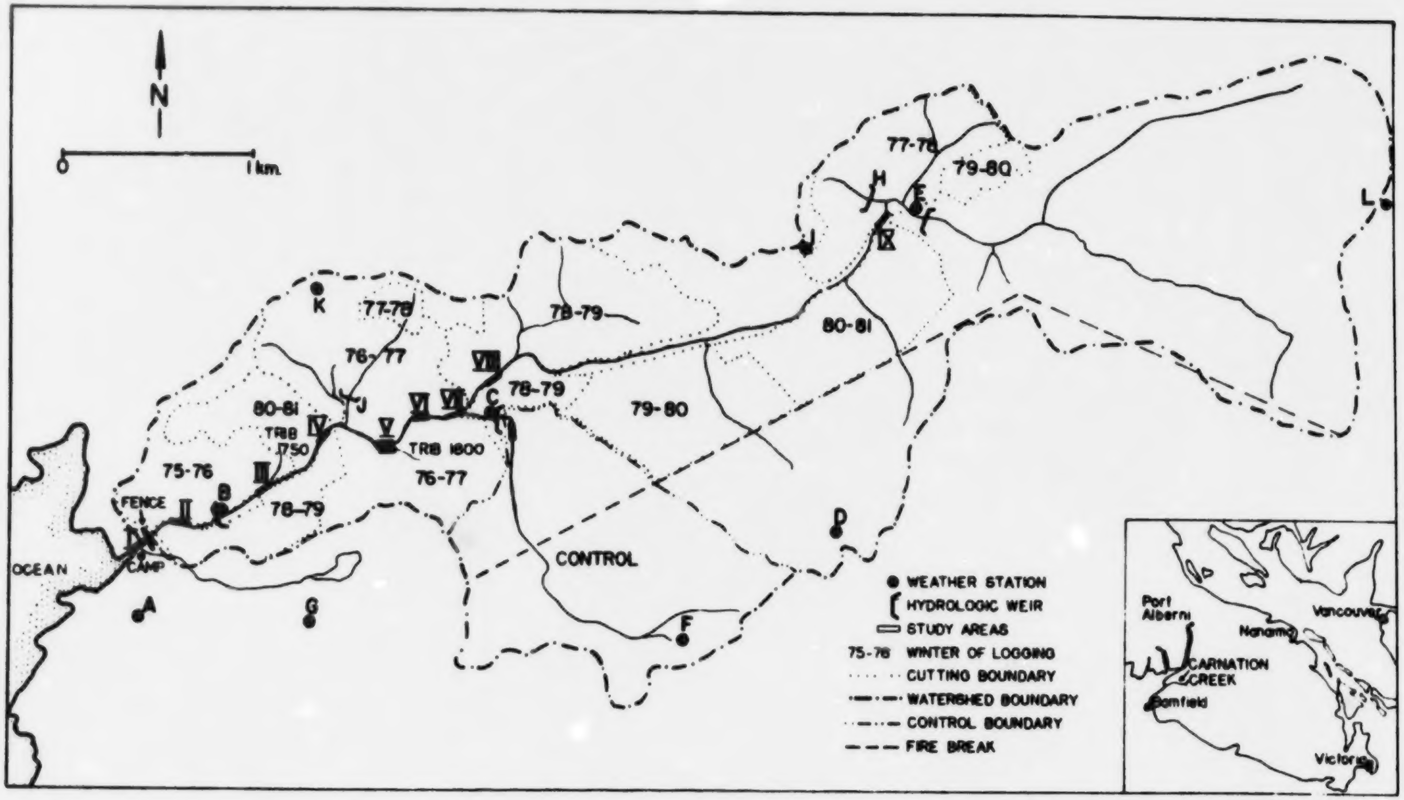
STUDY AREA AND LOGGING PLANS

Carnation Creek is a small salmon and trout nursery stream which flows into Barkley Sound on the west coast of Vancouver Island, B.C. (Fig. 1). The stream is about 7.8 km long and drains a watershed ~ 10 km^2. It is located within the Western Hemlock Biogeoclimatic Subzone (Krajina 1969) and is typified by coarse shallow soils, high annual precipitation (250 cm to 380 cm), little snowfall (< 5% of precipitation), and widely varying flows (0.017 m^3/s to 45 m^3/s). The major features of the watershed have been described in more detail elsewhere (Oswald 1973; Scrivener 1975; Bustard and Narver 1975).

Anadromous fish utilize the lower 3.1 km of stream encompassed by study sections I to VIII (Fig. 1). Chum salmon (*Oncorhynchus keta*) spawn mainly in section I, while coho salmon (*O. kisutch*) pass through the fence to spawn in areas represented by sections II to VIII. Study sections IX and C contain resident cutthroat trout (*Salmo clarki*). Small numbers of steelhead (*S. gairdneri*), searun cutthroat trout, and pink salmon (*O. gorbuscha*) spawn in the main channel. Coastrange sculpin (*Cottus aleuticus*) and prickly sculpin (*C. asper*) also occur in the lower main stream.

Timber harvesting began in the winter of 1975-1976 with a small clearcut near the stream mouth (Fig. 1). This initiated three basic streamside treatments in the area occupied by salmon and steelhead trout.

1. *Undisturbed streamside treatment.* This area was logged as 3 openings during 1975-1976 (23.0 ha), 1978-1979 (19.4 ha), and 1980-1981 (16.0 ha) and left the lower 1300 m of Carnation Creek with a small buffer strip or unlogged canyon area in which deciduous vegetation and a few merchantable trees remained. This area included study sections II to IV.
2. *Intense streamside treatment.* The next 900 m segment of streamside was logged in 1976-1977 as 2 large clearcuts (61.0 ha and 34.4 ha). This treatment included prelogging hand appli-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CONTROL BOUNDARY
FIRE BREAK
Port Alberni
Nanaimo
Vancouver
CARNATION CREEK
Bamfield
Victoria

Fig. 1. The location of Carnation Creek and a detailed map of the watershed showing monitoring sites, stream study sections, and cutting boundaries.

cation of Tordon 22K herbicide to girdled alder stems; falling all merchantable timber either away from the channel or, if leaning heavily, across the channel; and then yarding the timber away from the stream to roadside landings. This area included study sections V and VI.

3. *Careful streamside treatment.* Both sides of the next 900 m of streamside were logged as 2 clearcuts (63 ha and 13 ha) during 1978-1979. Here, minor vegetation such as salmonberry was left; 6 merchantable trees which could not be jacked or cabled were felled across the channel and removed; and alder was later felled and piled for burning during scarification. This area included study section VIII.

These low-elevation sites are winter logging shows and activity usually begins in September-October and ends in early May (Cameron Division 1979). High-lead cable systems are used in these areas. About 41% of the watershed had been logged upon completion of the last clearcut in May 1981. A more detailed description of the study sections is given elsewhere (Scrivener and Brownlee 1981; Toews and Moore 1982).

METHODS

Streamflow and water temperature were recorded at the hydrological weir at Station B (Fig. 1). Continuous records have been obtained of flow since April 13, 1971 and of water temperature since July 16, 1970. Water levels were traced by Stevens A-35 and A-71 recorders. Water Survey of Canada automated data processing techniques were used to extract and analyze the flow records (Ozga 1974). A Lembrecht 256C thermograph recorded temperatures and the charts were processed using similar computerized techniques. Mean daily water temperatures were then summed to produce the centigrade temperature units (CTU) reported here.

During 1971, a temporary counting fence with three inclined plane traps was used to obtain daily counts and 10-day length and weight measurements of coho fry and smolts leaving the stream. This structure was 100 m upstream of the permanent fish-counting fence which was built in March 1972 (Fig. 1). The permanent fence consists of flow divider screens and five fan traps capable of screening 6 m^3/s of water. At higher flows, known portions were subsampled. Fence construction and operations are explained more fully elsewhere (Lill and Sookachoff 1974; Hartman et al. 1982; Narver and Andersen 1974).

Large numbers of fry were caught at the counting fence a few days after they were first sighted by swimmers counting fish in the stream (Tschaplinski and Hartman, in press). These simultaneous observations indicated that early fence counts could be used to approximate the timing and magnitude of fry emergence. To approximate emergence and seaward movement timing, four Julian dates were extracted from the daily counts; start, 25%, 50%, and 75% of the fry run.

Lengths, weights, and population numbers used in this paper were obtained from population surveys in the study sections (Fig. 1). Each year, three or more of these surveys were completed: one in late May-early June, one in late July, and one in late September. Unfortunately, streamflow conditions did not permit completion of the surveys on exactly the same dates each year, but over the 11 years reported here, most surveys were done within the 12-day periods of May 17 to 29, July 21 to August 3, and September 12 to 24. Population surveys were initiated in sections II, III, VI, and VIII in 1970; in section IV in 1971; and in section V in September 1973. A lack of manpower prevented completion of the first survey in 1980.

Fish were collected by a combination of pole seining and electrofishing. The wetted area of riffles and pools in each section were measured during each survey. In 1970 and 1971, coho population estimates were determined by mark recapture methods. Later estimates were determined by removal method (Seber and LeCren 1967). A more detailed description of population survey methods is contained in earlier publications (Hartman et al. 1982; Narver and Andersen 1974).

During analysis, the data were divided either into two time periods—1970 to 1976 (prelogging) and 1977 to 1981 (during-logging); or into three time periods—1970 to 1976 (prelogging), 1977-1978 (postintense treatment to November 1978 freshet), and 1979 to 1981 (postfreshet). The November 1978 freshet was used to separate time periods because this was the first major freshet after the intense logging treatment. In some study sections, streambanks were eroded,

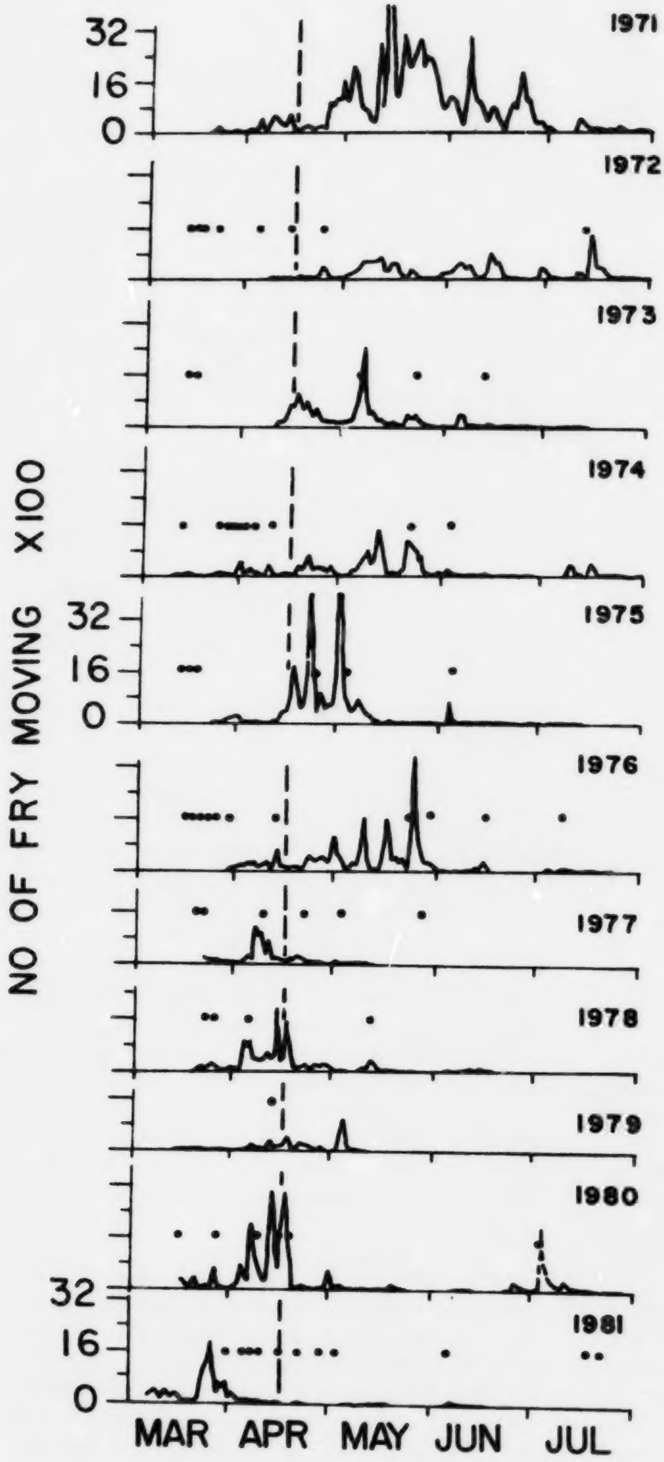

Fig. 2. Daily coho fry movement through the Carnation Creek counting fence in 1971 through 1981. Dots indicate the dates of freshets where peakflow exceeded 1.8 m^3/s. April 15 is emphasized with a dash line through all years.

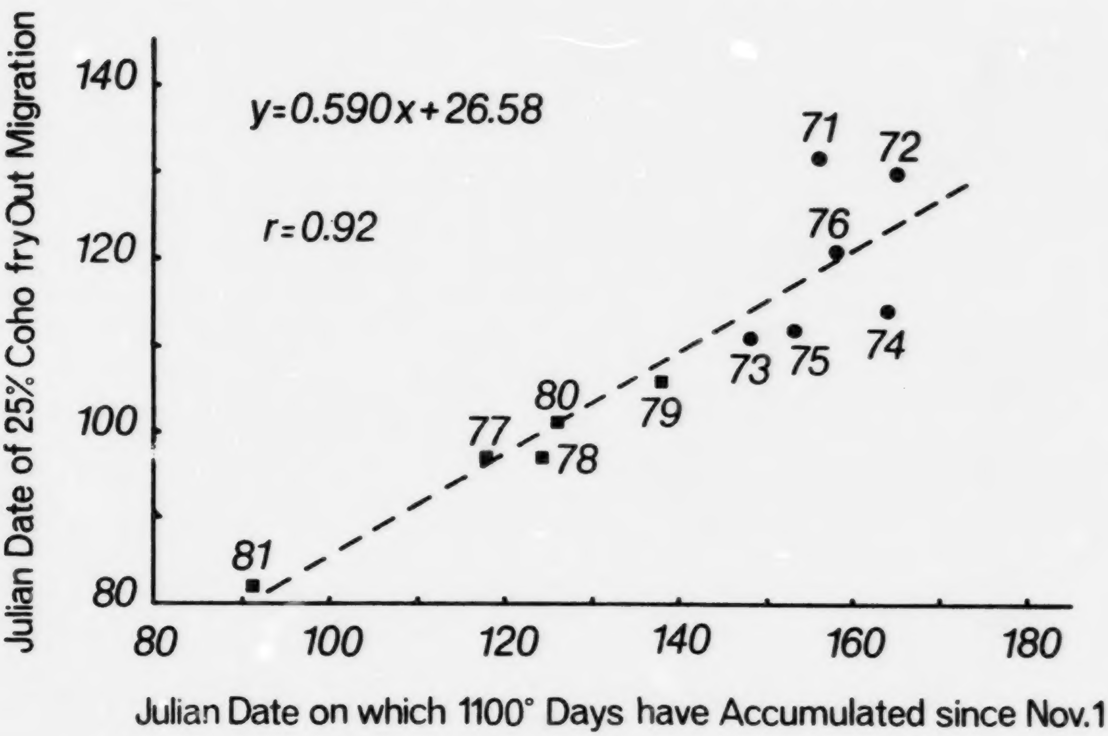

Fig. 3. The relationship between B-weir winter water temperatures in degree days and the initiation of coho fry emergence and emigration in Carnation Creek. Dots indicate prelogging years. Squares indicate during-logging years.

pools became shallower, gravel quality declined, and channelization occurred during this freshet (Schultz et al. 1981; Toews and Moore 1982). More recent freshets appear to be continuing these dramatic changes (Schultz et al. 1981; Scrivener and Brownlee 1982).

Most of the fish data used in this analysis were presented in earlier data reports (Andersen and Narver 1975; Andersen 1978, 1981).

RESULTS

Seaward Movement of Fry

From 1971 to 1981, the number of fry moving out of Carnation Creek varied widely on a daily and annual basis (Fig. 2). Fry movement took place from early March through August, but the major period of seaward movement occurred in April and May. With the exception of 1971 and 1974, the initiation of fry movement was earlier after 1976. Also, 90% of the fry run passed through the fence after April 15 in the prelogging years 1971 to 1976, but after 1976, 50% to 90% of the run occurred prior to April 15 (Fig. 2).

The influence of water temperature on emergence timing was explored by regressing the Julian date on which 1100 CTU had accumulated since spawning against the Julian date of 25% of the fry run. A significant positive regression Y = 0.59 X X 26.58 was obtained (r = 0.92, F = 46.0***, Fig. 3). Thermal summation was from November 1 because this date was usually included within the peak week of female coho escapement through the counting fence and the

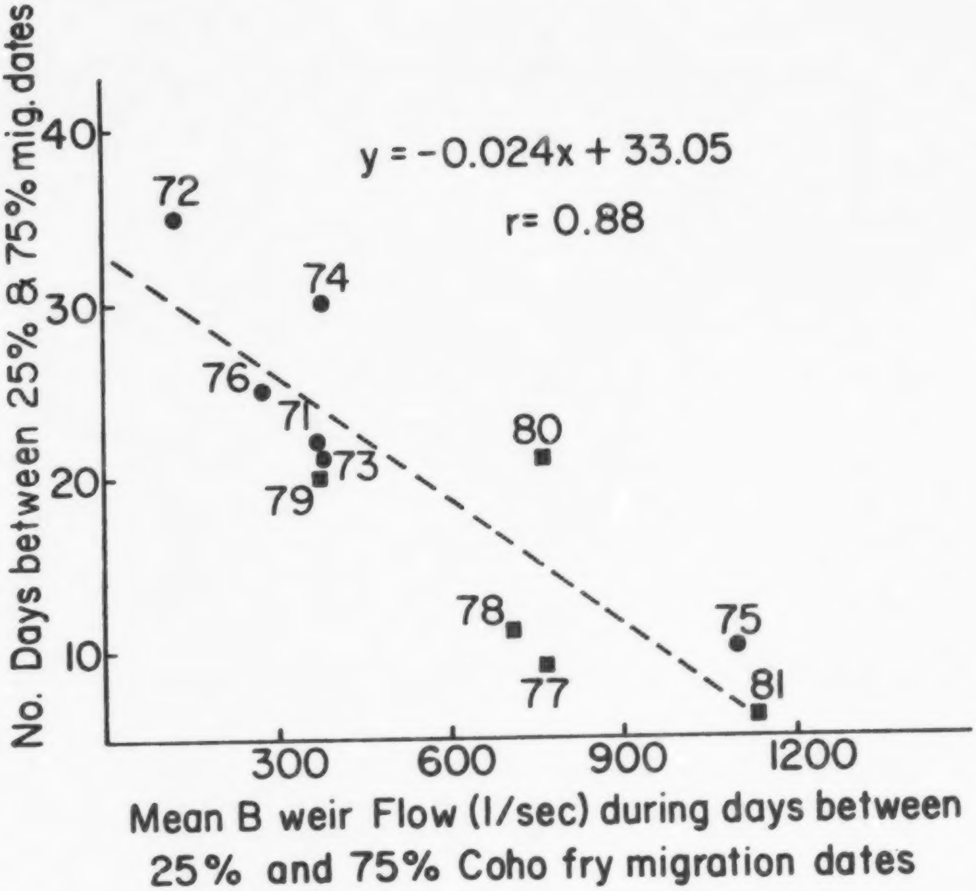

Fig. 4. The relationship between mean streamflow and the rate of half the coho fry loss from Carnation Creek. Dots indicate prelogging years. Squares indicate during-logging years.

apparent initiation of spawning. Between 60% and 90% of the total escapement had occurred by the end of the week, which included November 1. Under controlled temperature regimes, the average observed requirement for emergence of coho fry is 1100 CTU (Velsen and Alderdice, Pacific Biological Station, pers. comm.).

Both the dates of 1100 CTU accumulation and of 25% fry output were earlier in during-logging (1977 to 1981) than in prelogging (1971 to 1976) years (Fig. 3). A Mann-Whitney U-test probability of 0.002 (Siegel 1956) was obtained for either of these results occurring by chance. Therefore, the observation of more rapid CTU summation and earlier fry emergence in during-logging years is statistically significant.

Many peaks in daily fence counts appeared to be associated with storms and high flows, but fry numbers were often not proportional to flow magnitude (Fig. 2). In order to determine if flows were related to the fry movement, the number of days between 25% and 75% of the run was regressed against mean streamflow between the two dates (Fig. 4). An inverse relationship $Y = -0.024 X + 33.05$ was obtained ($R = 0.88$, $F = 29.2^{***}$). During springs of intense storms and high streamflows, the bulk of the fry loss occurred over shorter periods of time than during springs with fewer storms and lower flows. With the exception of 1975, the bulk of fry loss occurred more quickly in during-logging years 1977 to 1981 (Mann-Whitney U-test, $p = 0.015$).

Summer Numbers and Size of Fry

Table 1 shows population estimates of coho fry in the lower 3070 m of stream during spring, midsummer, and autumn. The underlined estimates were adjusted slightly from calculations of Andersen and Narver (1975) and Andersen (1978, 1980). This was done to provide estimates for the same weekly periods each year and was accomplished by subtracting numbers of fry known to have passed through the counting fence during the days of adjustment.

Between 1971 and 1981, the range of fry numbers in the stream was large, but three basic patterns emerged (Table 1). In 1981, 1977, and 1975, fry numbers were low at the time of the first population estimate. This was the result of either lower emergence or high initial losses through the counting fence (Fig. 2, Table 1). Numbers then declined slowly over the summer (Table 1). During 1980, 1979, 1978, and 1976, large numbers of fry remained in the stream throughout the summer and numbers declined gradually. In some other years (1972 and 1973), substantial losses between population estimates were obtained. These losses coincided with freshets and occurred immediately after the May population estimate in 1973, but occurred later in 1972 during July 14 and September freshets (Fig. 2, Table 1).

For 1971 to 1979, the number of fry in September ranged between 9 071 and 13 227 (Table 1). Subsequently, fry numbers were very high in 1980 and very low in 1981.

Fry lengths ranged from 38.1 mm to 46.2 mm in late May-early June and from 45.7 mm to 66.5 mm in late September (Table 2). In May-June, mean fry

Table 1. Numbers of coho fry in Carnation Creek in May-early June, late July, and late September population estimates. The asterisk indicates an estimate which excluded data from section II because storms prevented its completion until the second week in October.

	Population Estimate Period		
	Late May-Early June	Late July	Late September
1971	----------	----------	11 842
1972	33 556	15 442	9 252
1973	17 357	10 776	9 071
1974	18 004	14 580	12 584
1975	14 605	14 092	11 482
1976	46 662	19 173	12 327
			Mean = 11 093
1977	15 663	14 338	10 602
1978	26 148	23 120	10 927
1979	26 437	19 702	13 227
1980	----------	25 756	20 953
1981	6 647	6 995	6 088*
			Mean = 12 359

Table 2. Carnation Creek coho fry mean lengths during May-June and late-September population estimates both before and during logging activity. The t-test probability of the prelogging and during-logging means being the same are also shown. Since a May-June 1980 population estimate was not done, mean coho fry length at the counting fence was used.

	Date	Length (mm)	Date	Length (mm)
1971	May 8	39.7	Sep 15	48.1
1972	May 24	38.1	Sep 12	45.7
1973	May 18	39.5	Sep 12	50.6
1974	May 21	40.1	Sep 18	49.4
1975	May 21	40.1	Sep 18	54.3
1976	May 19	39.9	Sep 22	49.5
	Annual mean = 39.5		Annual mean = 49.6	
1977	May 17	41.8	Sep 26	59.9
1978	Jun 5	46.0	Sep 25	57.1
1979	Jun 4	45.2	Sep 19	58.0
1980	Jun 2	39.8 – Fence	Sep 17	51.7
1981	May 21	46.2	Sep 16	66.5
	Annual mean = 43.8		Annual mean = 58.6	
	p = 0.028*		p = 0.018*	

lengths were 39.5 mm during 1971 to 1976 and 43.8 mm during 1977 to 1981; while in September, they were 49.6 mm and 58.6 mm during the same years. Clearly, coho fry were larger both in spring and autumn during years of extensive streamside logging (t-test, p = 0.028, 0.018; Table 2). Fry were larger than these means during 1981 and 1975 when numbers had been low, while they were smaller during 1980 and 1972 when numbers were high (Tables 1 and 2).

Distribution and Growth in the Study Sections

The densities of fry in the study sections were highly variable among population estimates and among years. During late July, densities in study sections VI and VIII ranged from 4.8/m^2 in 1971 to 0.23/m^2 in 1981 (Fig. 5). In spite of this variability, three basic patterns were apparent. With the exception of 1971, densities in section VI were 1.1 to 1.9 times greater than those in section VIII for prelogging years (1970 to 1976). They were 2.2 and 2.1 times greater in 1977-1978 and were 0.3 to 0.9 times lower in 1979 to 1981 than those of section VIII (Fig. 5). The Mann-Whitney U-test probability that random factors explained the higher ratios in 1977-1978 was 0.056, and the lower ratios in 1979 to 1981, was 0.008. Therefore, in relation to section VIII, densities in study section VI were higher after the intense logging treatment, but they subsequently became significantly lower statistically after the November 1978 freshet.

The ratios of study sections VI to IV densities were also lower after 1978 (Fig. 5, Mann-Whitney U-test, p = 0.024). Therefore, after the November 1978 freshet, densities in section VI were lower in relation

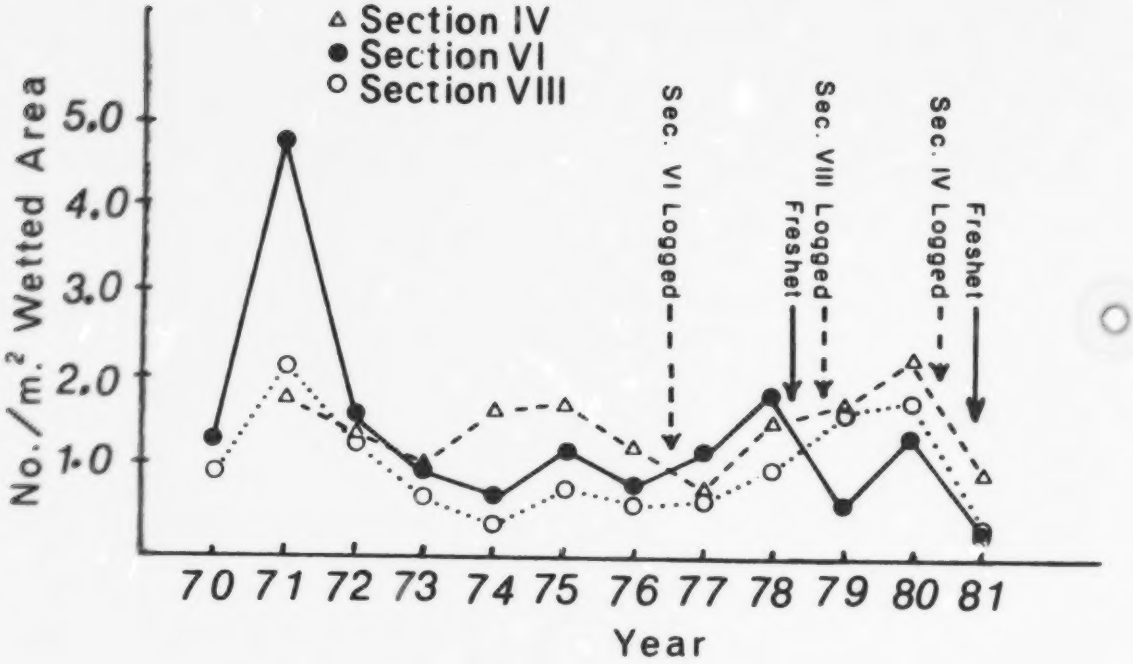

Fig. 5. Late July densities of coho fry in Carnation Creek study sections IV, VI, and VIII. The winters of adjacent logging and major freshets are indicated.

to the section immediately above and below the intense logging treatment.

A more complete picture of the impact of the intense logging treatment on densities in study sections V and VI can be determined from the September data (Table 3). Densities from 1973 section VIII and 1981 section II had to be obtained from an estimated population because of difficulties with equipment or interfering storms. These estimates were obtained from a regression of the proportion of the total population (Table 1) found in the study section against the date of the population estimate. Proportions from all other population surveys done during that year and those of the two following and preceding years were used in the regressions ($r = 0.87$).

The same three basic phases within the intensely treated sections were observed in the September data. When those densities in sections V and VI are expressed as percentages or ratios of those from sections IV and VIII (the sections immediately above and below the intense treatment), values ranged from 73% to 134% during the prelogging years 1971 to 1976 (Table 3). These percentages increased to 265% and 135% in 1977 and 1978 respectively after the intense streamside logging of sections V and VI. During 1979, 1980, and 1981, densities in these sections dropped to 38%, 67%, and 67% respectively of those in sections IV and VIII. In sections V and VI, densities increased significantly after logging ($p = 0.036$) and then dropped significantly below prelogging years ($p = 0.012$) after the November 1978 and subsequent freshets began making changes in these channel sections.

A similar pattern was obtained when densities in sections V and VI were expressed as a percentage of sections II and III (Table 3). Densities within the intense treatment were higher in relation to sections II and III ($p = 0.056$) during 1977-1978, but they were lower during 1979 to 1981 ($p = 0.058$), respectively, than in the prelogging years 1970 to 1976.

Densities of sections IV and VIII expressed as a percentage of those in sections II and III did not show

Table 3. Carnation Creek September coho fry density no./m^2. Study sections IV and V were established in May 1971 and September 1973 respectively.

			IV + VIII					V + VI	V + VI
	II	III	II + III%	IV	V	VI	VIII	IV + VIII%	II + III%
1970	0.89	1.18	101%	------	------	1.73	1.05	-----	167%
1971	1.14	0.82	73%	0.44	-------	0.96	0.99	134%	98%
1972	0.60	0.59	157%	1.01	------	1.01	0.86	108%	169%
1973	0.61	0.52	165%	1.05	0.44	0.93	0.81[a]	73%	121%
1974	0.66	0.75	138%	1.27	1.00	1.30	0.68	118%	163%
1975	0.61	0.38	168%	0.98	0.86	1.00	0.68	112%	188%
1976	0.72	0.58	107%	0.92	0.88	0.69	0.47	112%	121%
1977	0.24	0.30	137%	0.44	1.18	0.78	0.30	265%	362%
1978	0.45	0.35	126%	0.74	0.66	0.70	0.27	135%	170%
1979	0.72	0.60	157%	1.14	0.29	0.51	0.94	38%	60%
1980	0.70	0.98	211%	1.97	1.24	1.15	1.58	67%	142%
1981	0.31[a]	0.43	128%	0.65	0.38	0.26	0.30	67%	86%

[a] Due to sampling difficulties, these densities are derived from estimated population numbers.

the same patterns (Table 3). Significant differences were not found between the periods 1970 to 1976 and 1977-1978 ($p = 0.44$), between 1970 to 1976 and 1979 to 1981 years ($p = 0.192$), nor between 1970 to 1978 and 1979 to 1981 ($p = 0.188$) when adjacent logging occurred.

The measurement of fry from most study sections prior to September 1973 and from all sections after September 1973 permitted examination of growth by individual study section. Instantaneous 30-day growth rates were obtained from the formula $GL = \log e\ (L_2/L_1)/(\text{Date}_2 - \text{Date}_1/30)$. Fry lengths were used from the May-early June and September population surveys. Four significant relationships were obtained for sections II, IV, VI, and VIII when growth rates were regressed against the geometric mean annual summer fry density (Fig. 6). Analysis was not completed on sections III and V because less than 10 summers of growth data were available. Geometric means were used because the decline in numbers and densities of coho fry populations observed during spring and summer tended to fit a geometrical progression better than a linear progression (Table 1; Chapman 1965).

In order to test differences in growth rates between study sections and between prelogging and postlogging years, a covariance analysis was completed using the 4 study sections and the 2 periods as grouping factors, with density as covariate. These time periods were slightly different for each study section because the sections were logged at different times (Fig. 1). First, an analysis of variance of regression coefficients (growth rate or density) showed the regressions did not differ beyond chance between sections. Therefore, the growth rate data could be combined for all sections. The covariance analysis indicated a significant relationship between growth and density ($F_{1,38} = 48.9^{***}$), no difference between sections after adjustment for density ($F_{3,38} = 0.29$), a significant increase in growth after logging ($F_{1,38} = 4.5^{*}$), and no interaction between groups ($F_{3,38} = 0.38$).

In order to determine whether all the study sections contributed to the increased postlogging growth rates,

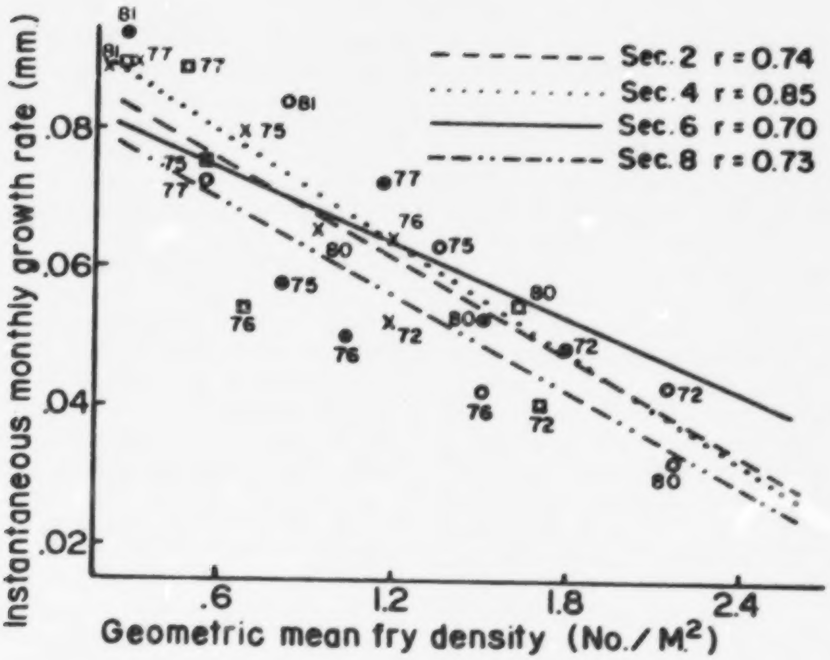

Fig. 6. The relationship between geometric mean coho fry density and instantaneous 30-day growth rate in Carnation Creek study sections II, IV, VI, and VIII. A few points discussed in the text are also shown.

the covariance analysis was repeated, excluding: first, section VIII data; second, section VI data; and, third, section IV data. The relationship between growth and the covariate density was still always apparent (minimum $F_{1,28}$ = 30.9***). The increase in postlogging growth rates was no longer significant ($F_{1,28}$ = 2.02) when section VIII data were excluded. They were significantly greater at the 0.1 and 0.05 probability level when section VI ($F_{1,28}$ = 3.9, p = 0.059) and when section IV ($F_{1,29}$ = 5.42*) respectively were excluded. Therefore, even though postlogging growth rates tended to be greater in all study sections, they were significantly greater statistically only in study section VIII after adjustment for the impacts of density on growth. Study section VIII also had the lowest overall growth rates and densities (Fig. 6).

Since density and growth rate were inversely related and since a wide range of densities were obtained (Table 3), growth rates varied from year to year (Fig. 6). During 1975, 1977, and 1981, growth rates (Fig. 6) were higher when densities and fry numbers in the stream were low (Table 1). In years such as 1972, 1976, and 1980, growth rates tended to be low when numbers and densities were high.

DISCUSSION

The results of this study indicate a number of factors influencing the emergence, movement, numbers, size, distribution, and growth of coho salmon fry which ultimately determine number and size of those fry in September. Some of these factors can be affected by logging. One factor is the timing of emergence which is related to winter temperatures. Another is discharge as it effects movement of fry out of the stream. The distribution of fry in the study sections is influenced by logging, specifically the intense treatment. Growth rates, which are related to density, and length of growing season determine fry size in autumn and are both influenced by logging.

Emergence and Seaward Movement

From 1977 onward, fry appeared at the fence earlier and usually stopped moving sooner than in prelogging years. This did not appear to be the result of earlier egg deposition or stress-related early emergence (Hartman et al. 1982). Egg-to-fry development was more rapid and related to the increased winter water temperatures observed since 1975-1976. Generally, warmer climatic influences occurred in during-logging years, but they could account for only part of these temperature increases. Observed water temperatures were higher than predicted from climatic influences during all five during-logging winters (1976-1977 to 1980-1981) and significantly higher statistically during two of these years (Hartman et al., in press; Holtby and Newcombe 1982). Much of this increase was attributed to the influence of logging.

The maintenance of adequate fry stocks in the stream could be adversely affected by shifting the period of emergence into the stormy March-early April period. The early rapid loss of fry during freshets apparently resulted in the stream being understocked in 1981. It has been demonstrated that coho fry in Carnation Creek tended to move seaward mainly during freshets (Hartman et al. 1982). It has also been demonstrated that fry emerging earlier in the spring have an increased probability of encountering high flows (Hartman et al., in press). Results here indicated that during years of intense storms and high streamflow, the bulk of fry loss to the stream occurred earlier than in years with few storms and lower flows. The flow conditions at the time of emergence appear to have an important impact on how quickly fry numbers are reduced during spring.

In 1975, 1977, and 1981, the major loss occurred so quickly that it is unlikely that density-dependent displacement influences of territoriality and aggression described elsewhere (Mason and Chapman 1965, Chapman 1962) could have had time to influence movement. Later or during other years, aggressive interaction probably served to force fry into less favorable habitat in the stream, but these were usually displaced downstream and through the counting fence during periods of freshet (Hartman et al. 1982).

Displacement during periods of low light intensity or lunar phases, as suggested by Mason (1975) for Lynn Creek, was not observed at Carnation Creek (Hartman et al. 1982). An understocking of coho fry in the Clearwater system appeared to result from a combination of low adult escapement and reduced egg-to-fry survival which was attributed to increased fines from heavily used logging roads (Cederholm et al. 1981). In Carnation Creek, understocking in 1981 was attributed to a logging-influenced reduction in egg-to-fry survival (Scrivener and Brownlee 1981, 1982) and high flows during emergence.

Summer Distribution of Fry

Changes in fry densities within study sections of the intense logging treatment coincided with observed alterations in organic debris distribution and in channel morphology. After the intense logging treatment, the volume and stability of large organic debris in sections V and VI were reduced (Toews and Moore 1982). The debris consisted of more individual and much smaller pieces. It had remained relatively unchanged in other sections (Toews and Moore, in press). Photos also indicated that substantial quantities of fine debris such as branches and deciduous vegetation had been introduced to sections V and VI. Coincident with these debris additions, 1977 summer fry doubled in relation to other sections. Fry densities were greater probably because the additions of scattered fine debris divided the stream into physically, more complex habitat which supported greater numbers. This impact was still apparent during the summer of 1978, after a winter of few freshets.

Major reductions in the volume of debris and changes in channel morphology occurred after the first large during-logging freshet in November 1978 (Toews and Moore, in press; Schultz et al. 1981). Streambanks were eroded, pools were shallower, and the channel was straightened in these study sections. Fine debris had accumulated in piles at a number of locations by 1979 and these were reduced in volume by a factor of 10 between 1979 and 1981 (Schultz et al. 1981). Coincident with these changes, fry densities in relation to the other study sections were reduced to about a half of prelogging values. Channel and streambed changes appeared to be continuing in 1980-1981 (Scrivener and Brownlee 1982). Stream channelization in Washington State has been shown to reduce coho densities in some creeks (Cederholm and Koski 1977), but not biomass in others (Chapman and Knudsen 1980).

Summer Growth and Size of Fry

Densities appeared to have a large influence on growth rates in all study sections. After adjustment for density, postlogging summer growth rates were significantly greater only in section VIII. This section also had the lowest observed prelogging rates. Despite this very modest influence of logging on summer growth rates, fry were much larger in September. These observations suggested that it was the earlier during-logging emergence and, therefore, longer growing season that had the greater impact on September sizes rather than improved summer growth rates. The size of fry at the end of May had the greatest impact on size in September when these influences were portioned (Hartman et al., in press). Fry were larger after 1976 because of a combination of a longer growing period and higher spring growth rates. The more rapid reduction in fry numbers in during-logging years probably contributed to these higher spring growth rates.

GENERAL DISCUSSION AND SUMMARY

Results from this study support recent hypotheses of two groups of logging-related influences which have appeared in the literature (Chapman and Knudsen 1980; Murphy and Hall 1981; Murphy et al. 1981; and Martin et al. 1981). Opening of the canopy over a stream tends to improve the rate of energy transfer in the biological community. As a result, microbial respiration, primary production, densities of benthos, drift of food organisms, and densities of predators including salmonids can all increase. These impacts are most apparent when heavily shaded, oligotrophic, higher gradient, boulder substrate first-order streams are exposed to sunlight and they become less apparent in more open, lower gradient second- and third-order streams. The impacts are short-lived (1 to 15 years after logging) and disappear as the driving forces of sunlight on the stream and the increased free nutrients are reduced by the second-growth forest.

The second group of logging impacts are related to habitat changes and their influence is usually negative. These impacts are usually of longer duration and can still be apparent 35 to 50 years after logging. They are most pronounced in low-gradient streams where mechanical energy may not be adequate to transport introduced fines which then accumulate in the gravel; or in streams which are dependent on woody debris to provide, first, channel and bed stability and, second, stable cover or surfaces on which stream biota depend. It probably takes more than 60 years before new large organic debris begins falling into the stream to replace losses due to logging. In higher gradient streams or rivers, large boulders help to perform these stabilizing functions. This dichotomy of influences into energy and habitat-related impacts aids in our understanding of the mixture of positive and negative influences observed at Carnation Creek.

The mechanisms affecting size and number of fry reported in this paper can be summarized by presenting various annual scenarios observed at Carnation Creek. During the prelogging years 1972 and 1976, fry emerged late in the spring after the freshets. This resulted in a shorter growing period and a prolonged period of fry movement through the counting fence. The high densities produced low growth rates and smaller-than-average fry in September. Freshets in late July and August 1972 produced high losses through the counting fence and thereby both small size and numbers in September. During 1975, fry emerged earlier because of warmer winter water temperatures and were exposed to freshets which rapidly reduced numbers. Few losses later in the summer left below-average prelogging densities, but the resulting higher growth rates and longer growing period produced the largest prelogging fry in September. In during-logging years 1977 and 1981, fry emerged very early after warm water temperatures but were immediately exposed to freshets. These rapidly reduced numbers and densities were very low in September. Low densities induced high growth rates which, coupled with the longer growing period, produced the largest fry in September. During 1980, emergence of very large numbers of fry was obtained from double-the-average adult escapement. This left large numbers in the stream even after substantial loss over a long period of time. As a result, numbers and densities in September were very high. Growth rates were very low, but the long growing period produced fish that were within the prelogging size range.

These wide-ranging scenarios indicate how critical it is for resource managers to understand the processes which influence coho populations before they plan forest harvesting or assess the impacts of logging.

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WINTER DISTRIBUTION OF JUVENILE COHO SALMON *(ONCORHYNCHUS KISUTCH)* IN CARNATION CREEK AND SOME IMPLICATIONS TO OVERWINTER SURVIVAL

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ABSTRACT

Coho populations in streams are reduced substantially in winter compared to numbers which occur in summer. Most of this reduction occurs early in autumn with the onset of the first seasonal freshets. Stream sections containing adequate winter habitat in the form of deep pools, logjams, and undercut banks with tree roots and debris lost fewer fish during freshets and maintained higher numbers of coho in winter than sections without these habitat characteristics. These features provide shelter and reduce stream velocities. Microhabitats occupied by coho juveniles in winter after logging were unchanged from those described before logging—all microhabitats were characterized by low water velocities (≤ 0.3 m/s). Up to 48% of the coho population inhabiting stream sections with adequate shelter remained there by midwinter (January 3). This survival rate was typical of stream sections where at least some trees remained after logging. Streamside trees stabilized the banks and prevented their collapse. In contrast, 2 of 3 study sections which had been clear-cut logged had unstable banks which collapsed during winter freshets. Coho were almost eliminated from these sections in winter.

Concurrent with seasonally declining fish populations in Carnation Creek, many coho emigrate from the main stream to seek the shelter of quiet tributaries and valley sloughs in autumn. This seasonal shift in distribution reverses in the spring when large numbers of coho reenter the main stream. Fish overwintering in these sites have a high survival rate. In the 750 m site before logging, a 4-year mean of 169 ± 44 coho entered in autumn; of these, 72.2% survived the winter. During logging, an annual mean of 288 coho entered the same site. The survival rate during logging was 67.4%, essentially unchanged from the prelogging value. Logging has neither reduced the numbers of coho juveniles which enter such sites in autumn to overwinter nor reduced the numbers leaving these sites to reenter Carnation Creek in spring.

INTRODUCTION

Juvenile coho salmon (*Oncorhynchus kisutch*) occupy a wide variety of stream habitats in summer. Areas occupied include pools (with or without bank cover), slow-moving riffles and side channels, midstream locations, locations under or near banks, and areas jammed with logs and other large debris (Hartman 1965, Ruggles 1966).

Several investigators have documented that stream-dwelling coho undergo seasonal shifts in distribution (Bustard and Narver 1975a, b; Mason 1976). Spatial requirements in winter differ from those in summer (Mason 1976). Mason (1966) reported that, during winter when water temperatures were low (5° to 8°C in Oregon), coho fry aggregated near the bottoms of pools in the main stream, remained close to each other, and were quiescent. Bustard and Narver (1975a) demonstrated that young coho in autumn moved into deep, slow-moving water as stream temperatures declined and discharge volumes increased. These investigators concluded that coho in winter must avoid (a) downstream displacement and physical injury during freshets (floods) and (b) predation by birds and mammals. They determined that important overwintering sites are (1) under banks, along stream margins where water movement is slow (≤ 0.15 m/s); (2) flooded sloughs in the stream valley which contain rooted vegetation; and (3) quiet side channels and small tributaries which sometimes contain flowing water only in winter. Coho also seek the shelter provided by large masses of debris (e.g., tree roots and logs) as seasonal water temperatures fall (Bustard and Narver 1975a).

Logging may affect the overwinter survival of coho by several methods. For example, Toews and Moore (1982) have shown that logging operations along stream sections in which (1) all trees are removed to the banks and (2) felled trees are removed from the stream eventually result in less debris accumulating in the stream and also cause debris masses to be less stable compared to stream sections not subjected to such logging practices. Winter freshets may thus remove debris cover and erode banks more readily after logging than in unlogged watersheds.

Because banks and debris cover provide overwintering habitats important to juvenile coho (Bustard and Narver 1975a) and given that some logging practices may eliminate or alter this cover (Toews and Moore 1982), logging can potentially reduce populations of stream-dwelling coho in winter. Therefore, the first objective of this research was to describe the numbers and distribution of coho juveniles overwintering in selected sections of a British Columbia coastal stream in relation to (1) the distribution of freshets and (2) different logging practices applied in each stream section.

Bustard and Narver (1975a) demonstrated that large numbers of juvenile coho salmon leave the main stream in autumn to enter side channels, sloughs, and tributaries to overwinter. The same coho then reenter the main stream in spring. Bustard and Narver (1975a) reported that coho which moved into these sheltered habitats in autumn survived the winter at twice the rate as those which remained in the main stream.

The second objective of this paper was to compare the numbers of coho entering sloughs and tributaries in autumn with numbers reentering the main stream in spring for several years both before and during logging. Overwinter survival rates of coho juveniles before logging were quantified and compared with rates occurring during logging.

THE STUDY AREA

Carnation Creek is a small stream about 7.8 km long, flowing into Barkley Sound on the west coast of Vancouver Island. The stream drains an area approximately 10 km^2 in the "Coastal Western Hemlock Biogeoclimatic Zone" of British Columbia (Hartman et al. 1982). Annual precipitation varies from 250 cm to 380 cm, most of which falls between early September and late March. Discharge volumes fluctuate rapidly and widely during winter from about 0.2 m^3/s up to 46.0 m^3/s during frequent winter freshets. The area, stream, and fish populations are documented by Hartman et al. (1982).

Two areas in the Carnation Creek valley inhabited by many coho fry ("age 0" fish, Bustard and Narver 1975a, b) and yearlings ("age 1+" fish, Bustard and Narver 1975a, b) are a slough located 750 m upstream from the mean summer high tide mark (called "750 m site") and a quiet tributary at 1600 m (called 1600 Tributary). These sites are as described by Bustard and Narver (1975a), except that clear-cut logging has removed all trees from both areas and much debris from logging occurs in 1600 Tributary. The 750 m site consists of temporarily flooded channels (usually filled with water during autumn, winter, and spring) which meander through areas thick with rooted vegetation (sedges and grasses). Both sites also contain small shrubs which provide cover over the flooded channels (Bustard and Narver 1975a).

MATERIALS AND METHODS

Enumeration of Populations Overwintering in Carnation Creek

Visual counts of coho fry and yearlings overwintering in 5 selected sections in the Carnation Creek main channel were made from October 3, 1980 to March 20, 1981. The lengths of the study sections, amount of cover available to overwintering coho, and logging practices conducted at each site are summarized in Table 1. Counts were made in stream sections that represented two different methods of logging.

Section III and the site at the "B" hydrographic weir (section B) were at least partly "forested". A narrow strip of trees was present along the north side of the stream in both sections. Fewer trees were present along the south bank. Section B contained shallow

Table 1. Carnation Creek study sections used to enumerate overwintering coho. Section lengths, areas of bank and debris cover, debris volumes, and logging methods are included for each section. Two values for area and volume (plus seasonal mean values in parentheses) are given for "cover" in section VI due to the midwinter addition of new cover when a large root mass fell into the stream.

		Cover Available for Coho		Logging Method Employed	
Study Section	Length (m)	Area of Debris (m^2)	Debris Volume (m^3)	Streamside Strip of Trees (% of Bank Covered)	"Yarding" (Log Hauling) Across the Stream
B (at "B-weir")	38	26.0	46.0	100	None
III	62	41.0	37.0	80	None
VI	77	5.0 to 8.0 (6.5)	2.5 to 5.0 (3.8)	0	Yes (limited)
VIa	8	2.5	3.0	0	"
VII	27	2.0	2.0	0	"

pools overhung by grassy banks at its lower end. The upstream portion comprised entirely of a large pool with deeply undercut banks, large tree roots, and much debris in the form of jammed logs. The pool was close to 3 m deep in its center. Section III had a long riffle about 20 m in length and had deep pools with fallen logs and tree roots at its upstream end.

Three sections (VI, VIa, and VII) were located in a large clear-cut area where all trees had been removed up to the streambanks. No overhead cover from vegetation was present. Section VI was essentially a straight channel (77 m long) which contained rapidly flowing water when the discharge volume was > 0.5 m^3/s. This section contained little shelter in the form of pools or cover provided by undercut banks. Two small (often isolated) pools along the south side of the stream always contained coho juveniles and tree roots and debris. In contrast to these sites, sections VIa (immediately upstream from VI) and VII contained large debris and large root masses located in deep pools. The pools in section VIa also contained deeply undercut banks in which fish could take refuge.

Ten visual counts of resident fry and yearlings were made in each section during the course of the study. Observations were made by snorkeling in the stream. A hand-held flashlight aided in locating fish residing under banks and in other poorly lighted areas. Data were recorded by a field assistant. All sections were enumerated on the same day. All counts were made between freshet periods when the discharge volumes ranged from 0.12 m^3/s to 1.10 m^3/s. Four counts were made immediately after a major freshet to observe any changes in population numbers which may have resulted.

Visual counts were confirmed by estimates made of the sizes of the coho populations using the Seber-LeCren (1967) removal method. Population estimates were made in sections III and VI on September 16 to 17, 1980 and on October 9, 1980. Both "fry" (fish $<$ 1 year old) and older fish (e.g., yearlings) were distinguished visually. All fish $\geq$ 75 mm long were considered to be at least 1 year old. Water velocity measurements were taken in March using a Gurley "Pygmy" current meter in areas where fish had overwintered.

Enumeration of Coho
Overwintering in Slough and Tributary Habitats

A screen weir containing both "upstream" and "downstream" traps were each constructed at the confluence of 2 side-channel sites with Carnation Creek. The apparatus used is exactly as described by Bustard and Narver (1975a).

The traps at 750 m were checked from September to June each year from 1972 to 1981, except for March to June 1979 and January to June 1980 when no traps were operated. Traps at 1600 Tributary were operated only in 1972-1973, 1973-1974, and 1980-1981. Observations were made daily, except in cases when flood conditions made observations impossible or when periods of drought occurred and the traps were thus dry. In several instances, trapping was suspended for a number of days when the weirs and traps needed repair.

The daily numbers of coho fry and yearlings entering the 750 m site and 1600 Tributary from Carnation Creek and those leaving these areas were recorded for each observation. Fish were removed from the traps and then anesthetized in a 1:4000 aqueous solution of 2-phenoxyethanol. Fork lengths of each individual fish were measured (from the tip of the snout to the tail fork). Scale samples were occasionally collected from fish $>$ 65 mm long to confirm the age of larger individuals. Simultaneously, water depths at each weir were read directly from staff gauges, and water temperatures in both sites and in Carnation Creek were taken using simple mercury thermometers.

RESULTS AND DISCUSSION

Microhabitats selected by coho fry and yearlings in winter were unchanged from those described before logging by Bustard and Narver (1975a, b). Areas jammed with logs, undercut banks, and deep pools filled with upturned tree roots and other forest debris contained almost all the coho salmon which remained in the main channel of Carnation Creek during the winter. Coho did not inhabit areas under banks unless these sites contained tree roots and (or) lodged debris.

Yearlings were often found deeper under banks than were fry. The former also tended to occupy the deepest parts of pools (e.g., water depths $\geq$ 45 cm) more frequently than the younger coho.

All microhabitats occupied by fry and yearlings were characterized by low water velocities. Random checks revealed that almost all fish were found in water velocities $<$ 0.3 m/s. These largely qualitative findings are consistent with those reported by Bustard and Narver (1975a, b).

Figure 1 shows clearly that coho population numbers in Carnation Creek are reduced substantially in winter compared with numbers inhabiting the same main-stream areas in summer. Population estimates in sections III and VI revealed that most of this seasonal reduction occurs early in autumn (late September and October) with the onset of freshets and low water temperatures (Fig. 1). For example, numbers of fry after the 11 m^3/s freshet of September 28 were reduced by about 63% in section VI and 45% in section III. Similarly, numbers of yearlings in the same sections were reduced respectively by 74% and 40%. Losses of fish in the clear-cut section VI were much higher than in the partly forested section III.

Four major freshets occurred during the season studied. The first one (September 28) was the least in magnitude but resulted in the largest declines in coho numbers in the 2 sections enumerated (Fig. 1, sections III and VI). Extreme discharge volumes such as those which occurred later in the season (Fig. 1) are thus not required to produce large numerical changes in the stream population early in the season. Subsequent freshets removed successively lower absolute numbers of fish from all study sections (Fig. 1); however, large declines in coho numbers continued to occur during the second seasonal freshet on November 1 (24 m^3/s). For example, the loss of most of one large root mass during the latter storm coincided with a decline in coho numbers from 122 to 23 in section VIa. Following the freshet of November 1, visual counts showed that coho populations in all sections fluctuated at low numbers (Fig. 1).

Sections containing adequate winter habitat in the form of undercut banks with tree roots and debris and deep pools lost fewer fish during freshets and maintained higher numbers of coho than sections without these features. For example, between the census of October 3, 1980 and the third (and most severe) seasonal freshet on December 26, 1980, coho juveniles were almost eliminated from 2 clear-cut sections of stream. No coho fry were observed in section VI. This section of shallow, relatively swift water contained almost no shelter of the form described above. Coho numbers in the adjacent section VIa (immediately upstream) were similarly reduced to 1 yearling. The freshet which occurred on December 26 eroded large areas of bank and caused its collapse in this section. In contrast, about 27% of the fry numbers and 29% of the yearlings counted on October 3 in clear-cut section VII survived the same time period. A stable debris mass located in a deep pool provided shelter for overwintering juveniles.

Sections III and B contained all of the features described above, which give shelter to overwintering coho. These sections were partly forested and thus had areas where the banks were stable. In addition, both sites contained stable debris in the form of submerged logs. Forty-eight percent and thirty-two percent of the fry numbers observed on October 3 in sections III and B respectively had remained there on January 3, 1981.

Stream sections containing stable habitat and deep pools might provide a refuge for fish displaced downstream from areas (e.g., section VI) where adequate habitat and cover are lacking. For example, section III contained over 4 times more yearlings on January 3 than were observed on October 3. Both sections III and B contained substantially more yearlings during winter than in any clear-cut section. Between-section movements of fish were also important in reestablishing at least low numbers of coho in sections VI and VIa by mid-to-late winter. Fish had been virtually cleared from both areas earlier in the season. The addition of a new root mass into section VI after a bank had collapsed coincided with an increase in population numbers which stabilized at low levels from mid-January to late winter (Fig. 1).

During "midwinter" (December 1 to March 20) when populations were relatively stable, the number of coho in each section was positively and linearly correlated ($r = 0.982$, $p < 0.01$) to the amount of debris volume present (Fig. 2). Although this relationship is based on limited data (only 5 study sections with mean numbers of fish in each section derived from 7 enumerations), the data suggest that further investigation be undertaken. The investigation must include a complete range of cover volumes in different study areas to establish a more detailed and precise relationship. Coho numbers were not correlated significantly to area of bank and debris cover ($r = 0.83$, but $p > 0.05$).

Three factors can account for the large reductions in coho numbers from the study sections in autumn: (1) mortality due to physical injury caused by freshets, (2) displacement of fish to locations downstream, and (3) immigration into valley sloughs and tributaries. The large reductions in the main-stream population

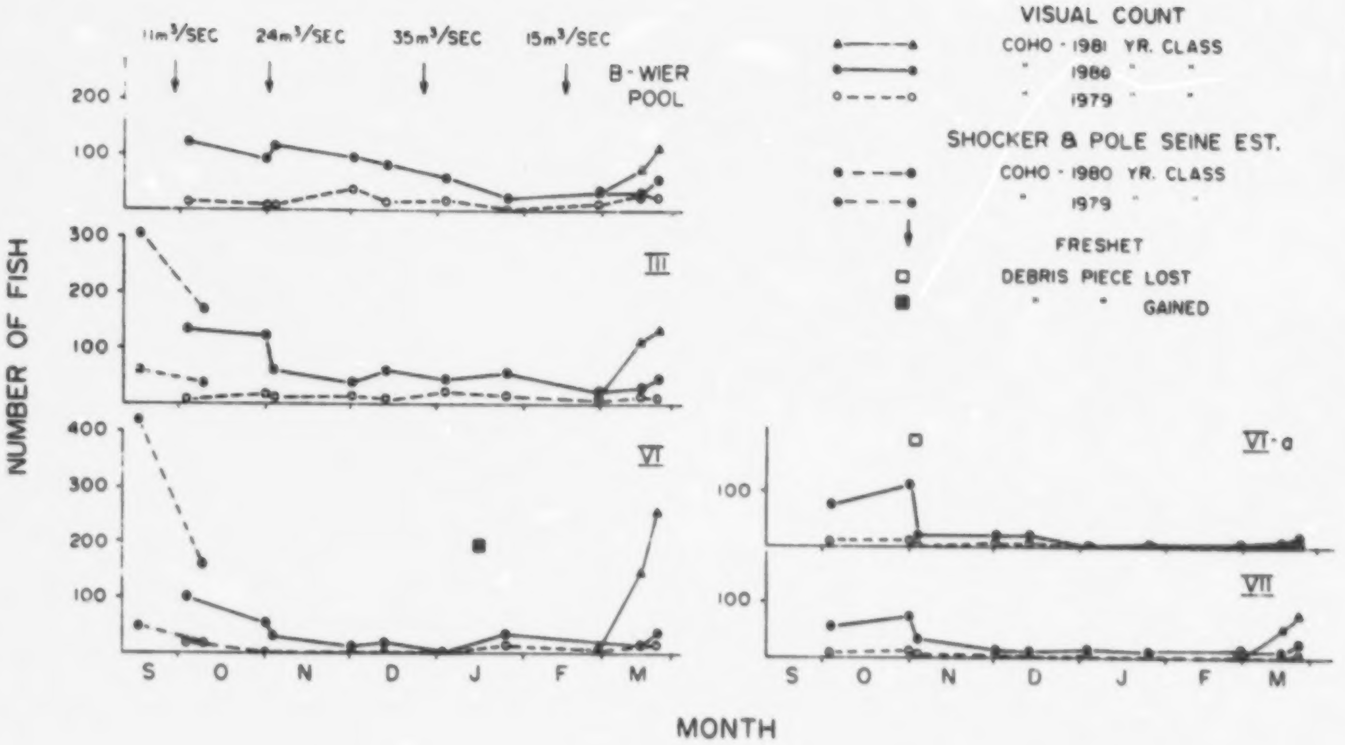

Fig. 1. Numbers of juvenile coho (1979 and 1980 year-classes) over-wintering in 5 selected sections of Carnation Creek during the autumn-winter of 1980-1981. In late winter, all sections included some new coho fry (1981 year-class).

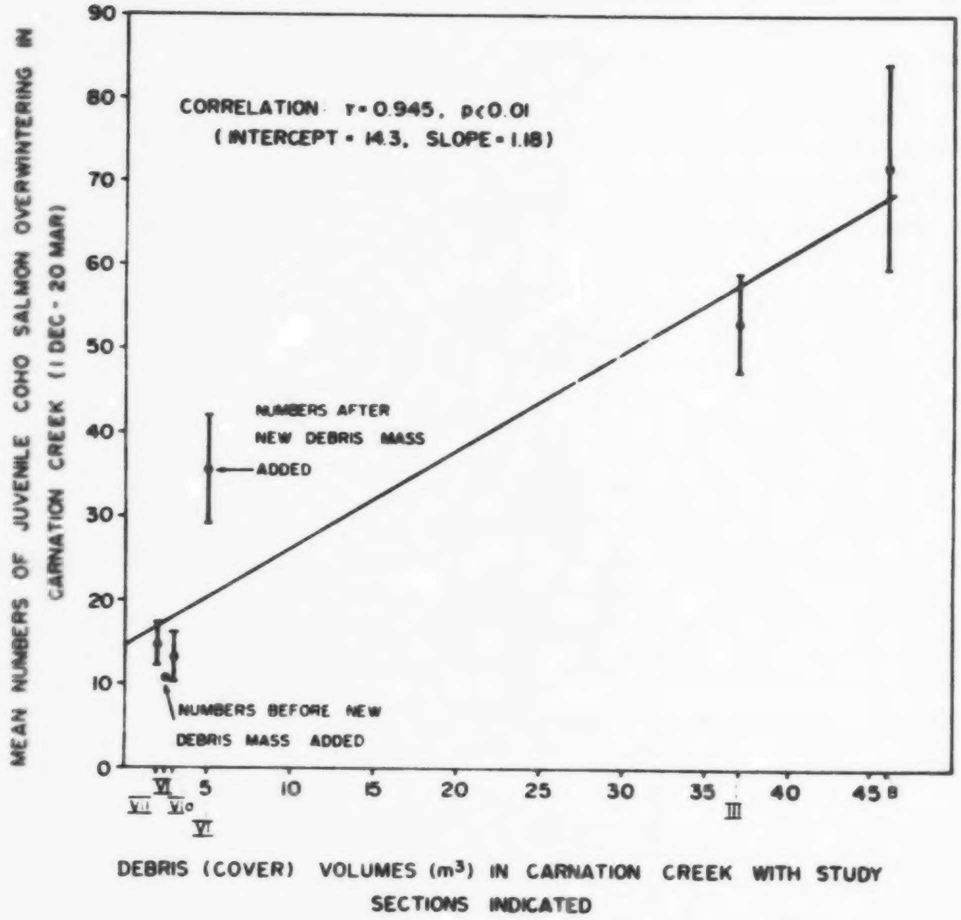

Fig. 2. Relationship between debris (cover) volumes and mean numbers of coho overwintering in 5 selected sections of Carnation Creek. Each mean (except those for section VI) represents 7 individual enumerations from December 1 to March 20 when population numbers were relatively stable. Two means are given for section VI. One represents fish numbers before the addition of new cover in the form of a large root mass (December 1 to January 3). This value results from only 3 enumerations and thus contains no ± standard error bars. The second value represents fish numbers after the root mass fell into the stream section. Coho numbers increased significantly over the previous value and over those in sections VII and IVa.

in autumn coincide with the largest movements of fry and yearlings into the side-channel slough at 750 m and into 1600 Tributary (Fig. 3). Coho which leave the main stream to overwinter in these sheltered habitats thus account partly for the low numbers inhabiting Carnation Creek during winter. However, the proportion of the total population which enters these areas is unknown because (a) not all sloughs and tributaries were studied and (b) actual fish movements from one main-stream site to another cannot be determined unless fish are marked for individual identification.

Figure 3 illustrates in detail the daily pattern of seasonal movements in 750 m site and 1600 Tributary. The largest movements of fish are generally coincident with peaks in discharge volumes in both spring and autumn. No qualitative differences in the patterns of fish movements are detectable between the prelogging year of 1973-1974 and the last year of logging (1980-1981). Large daily movements into these side-channel sites occur in autumn with the onset of the first seasonal freshets. These early peaks in stream discharge are usually much lower than those which occur in midwinter. This phenomenon indicates that the autumn increase in discharge volumes may be a seasonal cue for coho to seek shelter before the extreme discharge volumes occur later in the year. Daily movements from December to February are generally low. From February to May, large movements out from the side-channel sites occur (as shown by the monthly and seasonal data, Figs. 4, 5, and 6).

Figures 4, 5, and 6 summarize the data over monthly or seasonal intervals and illustrate long-term patterns. Figures 4 and 5 show that large numbers of coho move into the 750 m site and 1600 Tributary from September to December during both prelogging and logging years. Movements are bidirectional, but far fewer fish reentered the main stream of Carnation Creek from September to December. Figure 6 illustrates clearly that large net movements of fish into the 750 m site occurred during autumn to early winter.

In January and February, low numbers of fish move in either direction between Carnation Creek and the slough at 750 m. Fish are relatively inactive in midwinter (Bustard and Narver 1975a, Hartman 1965). However, from late winter to spring, the net movements are reversed from those shown in autumn (Fig. 6). Overwintering coho leave the 750 m site in large numbers to reenter Carnation Creek (Figs. 4 and 6). These seasonal shifts in distribution, first reported by Bustard and Narver (1975a) for early prelogging years, remain unchanged 5 years after the first logging operations began in 1976.

When prelogging (1972 to 1975) and during logging (1976 to 1981) periods are compared on a monthly basis from September to December, no clear differences in fish movements into the 750 m are distinguishable, except for September. Large increases in coho movements into the site occurred during postlogging in this month (Fig. 4). This observation may be due in part to sampling errors. Prelogging data were not collected for September 1974 and are incomplete for September 1973. (Similarly, traps were not operated in 1972.) Sampling problems notwithstanding, high between-year variation in the numbers of fish entering 750 m site occurred for all months and thus renders prelogging and postlogging mean movements to be statistically the same for October, November, and December (Fig. 4, ± standard errors for each month).

When monthly movements are combined to compare seasonal (autumn to early winter) net movements for prelogging and postlogging periods, new trends are shown (Fig. 6). The absolute numbers entering and leaving 750 m site are statistically equal for both periods (except in September); however, a trend toward higher net movement of coho into the overwintering site occurred after logging began in 1976 (Fig. 6). This increase is not statistically significant ($p > 0.05$).

Similar relationships are shown for the January to June monthly and seasonal movements. Because traps were not operated in 1978-1979 and in 1979-1980, only 3 years of data are available for March, April, and May-June postlogging (Fig. 4). Prelogging and postlogging periods, thus, cannot be treated statistically for the latter months. However, monthly averages for movements both into the 750 m site and out from it are virtually the same, except for May-June. Despite high between-year variation, a trend toward higher numbers of coho leaving the 750 m during logging occurs for March and April and becomes more pronounced in May-June (Fig. 4). This trend results in higher seasonal (January to June) net movements of coho out of the 750 m site during logging (Fig. 6). Although statistical comparisons (by analysis of variance) are not possible for this season, it is clear that logging has neither reduced the numbers of coho fry and yearlings which enter the 750 m slough in September to December to overwinter nor reduced the numbers leaving the

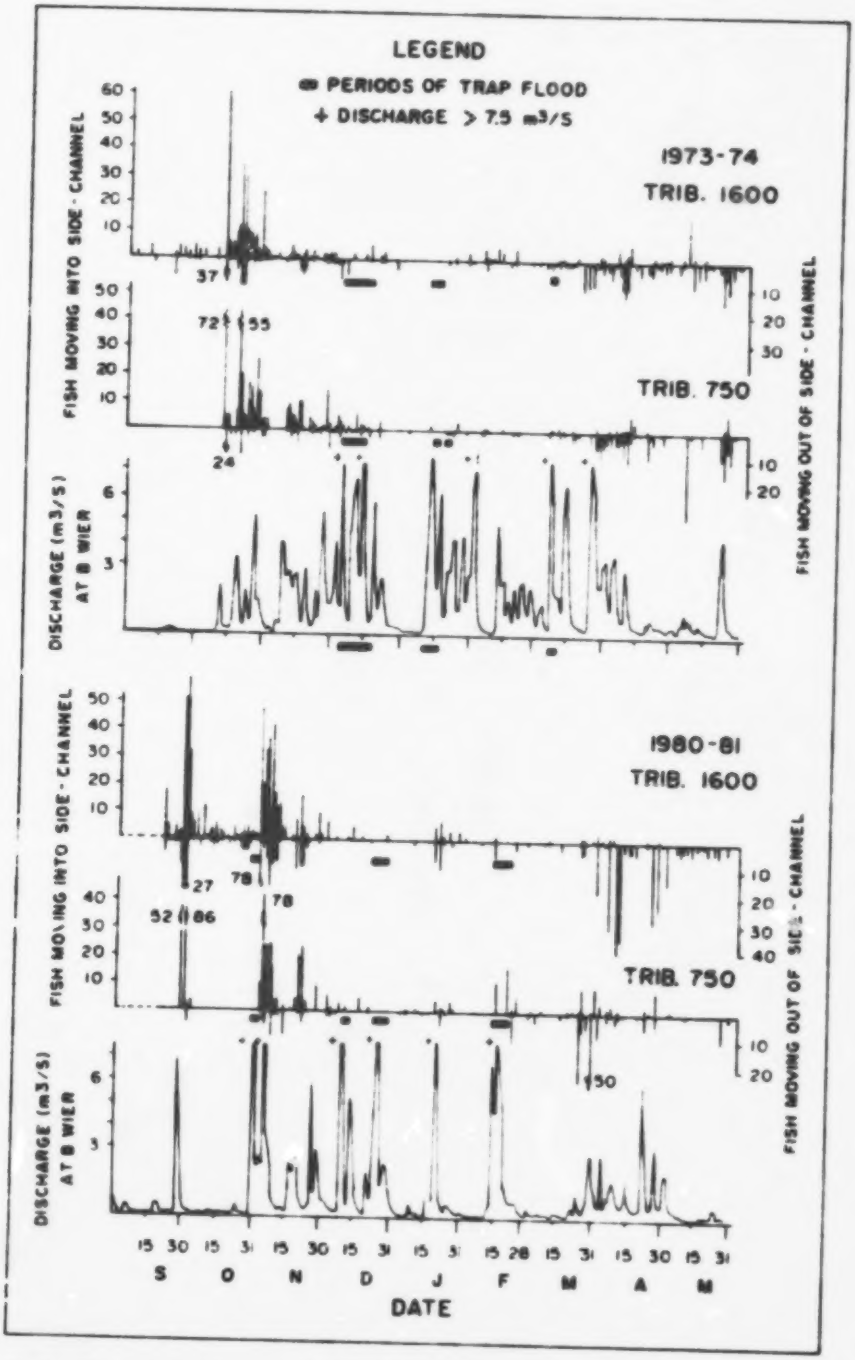

Fig. 3. Daily movements of coho juveniles (all ages combined) before logging (1973-1974, top) and after logging (1980-1981, bottom) between Carnation Creek and the overwintering sites at 750 m slough and 1600 Tributary. Stream discharge volumes are also plotted (m^3/s). Traps could not always be checked during periods of heavy flooding. Heavy solid bars indicate periods when traps were flooded and under water. When discharge volumes exceeded 7.5 m^3/s, a "+" symbol is indicated.

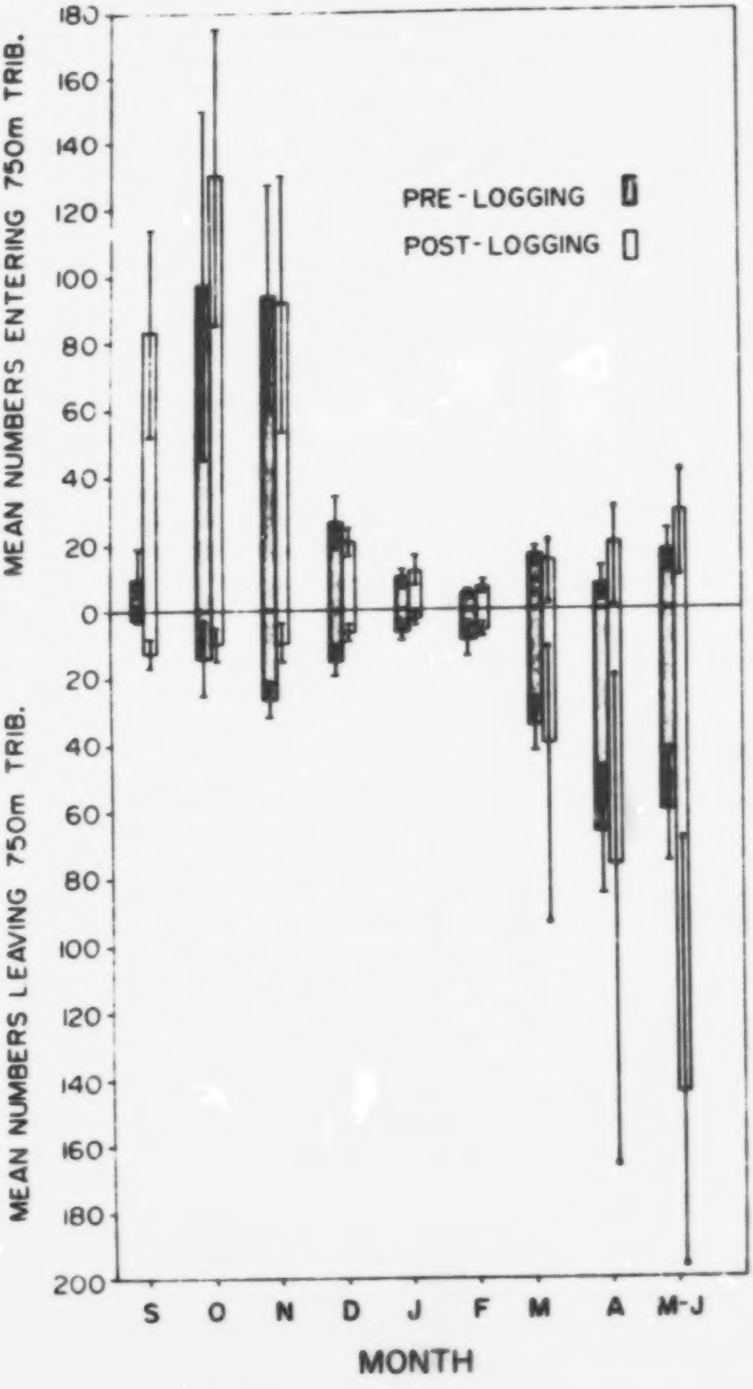

Fig. 4. Numbers of coho juveniles (all ages combined) moving into or out of the 750 m site. Histograms depict mean movements into and out from the 750 m slough. Shaded histograms represent prelogging years (1972 to 1975). Clear histograms represent years during logging (1976 to 1981). For September to December, means (with ± standard error) represent 4 years prelogging and usually 5 years when logging occurred. For January and February during logging, mean values (with ± standard error) represent only 4 years of data because traps were not operated in 1979-1980. For March, April, and May-June during logging, mean values represent only 3 years because traps were not operated in 1978-1979 and in 1979-1980. The latter mean values are bounded by ranges.

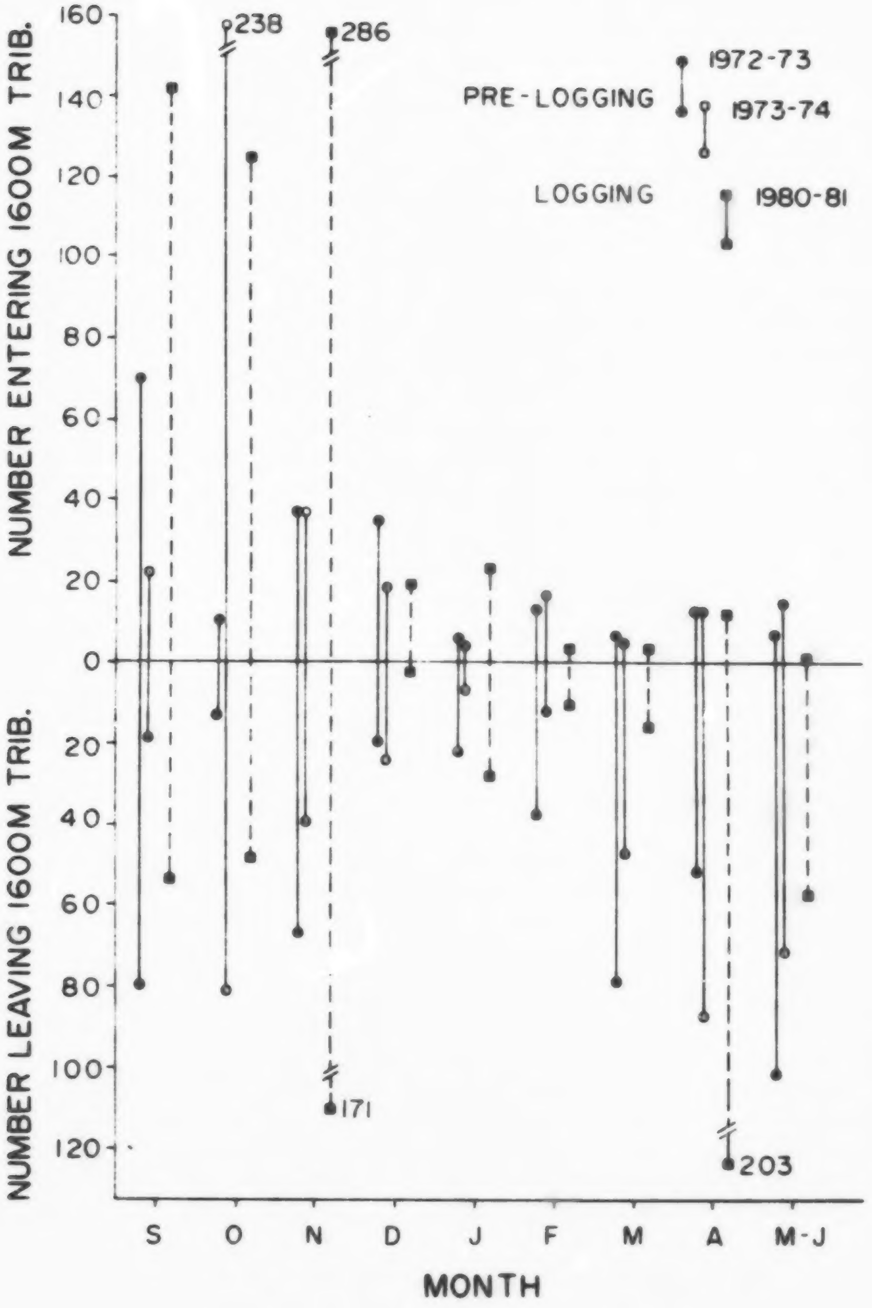

Fig. 5. Numbers of coho juveniles (all ages combined) moving into or out of the 1600 Tributary. Years before logging (1972-1973, 1973-1974) are represented by solid bars. A broken line represents 1980-1981. Data are given as discrete annual values.

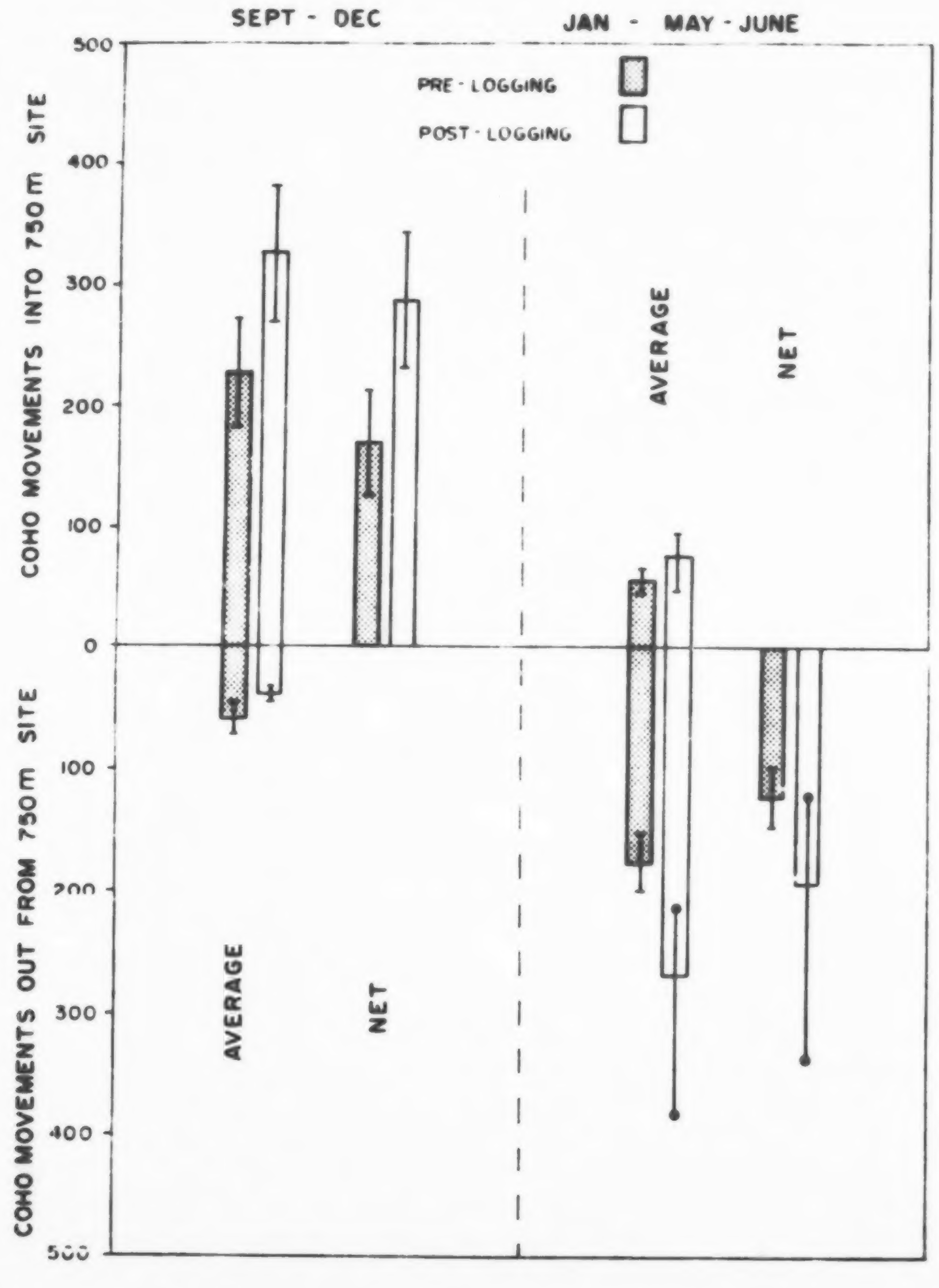

Fig. 6. Seasonal average and net mean movements of coho juveniles (all ages combined) into and out from the 750 m site. Shaded histograms represent prelogging years (1972 to 1975). Clear histograms represent postlogging years (1976 to 1981). Values are bounded by ± standard error bars, except for January-May-June postlogging. The latter means are bounded by their ranges because only 3 years of complete seasonal data are available.

site to reenter Carnation Creek from January to June. In contrast, trends toward higher numbers of fish using the overwintering site are suggested.

An annual mean of about 169 ± 44 coho entered the 750 m site from September to December to overwinter before logging occurred in Carnation Creek. On the average, 122 ± 15 coho reentered Carnation Creek from January to June during the same period of time. If these net seasonal movements can be taken as a rough measure of overwinter "survival", then these values indicate a "survival rate" of 72.2% for coho using the site during prelogging years. From 1976 to 1981, annual numbers of coho entering the same site in "autumn" and then leaving in the "spring" were about 288 and 194 respectively. The survivorship rate for the postlogging period was 67.4%, essentially unchanged from the prelogging value. Although logging had removed the forest cover at the 750 m site, the quality of the coho overwintering habitat did not appear to be altered to the degree that overwinter survival of the fish was affected adversely.

Only 3 years of data are available for coho movements in 1600 Tributary (2 years prelogging and 1 year during logging), but Figure 3 shows that no between-year trends can be distinguished. The seasonal and monthly patterns of coho movements, shown more completely by the data from the 750 m site, are repeated at 1600 Tributary. No obvious logging-induced changes have occurred in the numbers of juvenile coho overwintering in the latter site.

The seasonal movements of young coho described in this paper are consistent with those shown by Peterson (1980). In autumn, many coho are displaced downstream during freshets. Some of these fish are able to enter tributaries, sloughs, and quiet side channels to overwinter. These fish return to the main stream in spring, during (or before) the period when stream-dwelling coho transform into seagoing smolts. Peterson (1980) documented that the downstream movement of coho in autumn can occur over long distances (hundreds of metres). The coho he studied overwintered in large, spring-fed ponds.

This work and that of others (Bustard and Narver 1975a, b; Peterson 1980) show clearly that valley tributaries and sloughs are essential for the winter survival of many young coho salmon. Conservation of these features is essential in habitat enhancement efforts. These habitats should also be protected by forest-industry and road-construction operators. Forest managers should also ensure that large, stable debris masses (e.g., logs and tree roots), which occur normally in such streams as Carnation Creek, remain both during and after logging. Leaving a streamside "buffer strip" of trees after logging is important in the continued production of such debris. Streamside trees and other vegetation maintain the prelogging rate of bank erosion and reduce the potential for bank collapse.

Before logging, small numbers of adult coho and cutthroat trout (*Salmo clarki*) reproduced in 1600 Tributary. After logging, the channel became unsuitable for spawning because it had been filled with sediment and small debris (e.g., wood chips and tree bark). Given that adult fish spawn in such tributaries and that juveniles find refuge in them, forest managers must insure that they do not become obstructed by roads or blocked by undesirable materials.

ACKNOWLEDGEMENTS

Many people involved with the Carnation Creek Experimental Watershed Project contributed to this paper either directly or indirectly. The authors wish to acknowledge all of these persons and to express sincere gratitude to the following: Dr. Blair Holtby, Dr. Ian Birtwell, Dr. John C. Mason, and J. Charles Scrivener for reading and criticizing the manuscript; Dick Leahy, Bruce C. Andersen, Philip Neaves, and Andrew Witt for construction of fish traps, monitoring daily fish movements, and collecting stream temperature and volume discharge data; and Helen Hartman and Shawn Mason for assisting in data collection and the recording of field observations.

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QUESTIONS
TO P. TSCHAPLINSKI AND G. HARTMAN

Question *(P. Bisson)*: I'd like to offer a purely conjectural hypothesis and ask some of the people that have worked on fish to respond to it. The question has to do with the timing of coho fry out-migration. One of the previous speakers pointed out how the fry were moving out much earlier in the postlogging period than they were in the prelogging period. Several speakers today have referred to the coho fry as being swept out of the stream in high-flow periods. I am wondering what the impact of turbidity is on the behavioral responses of the fish. And I'm particularly thinking of the evidence that Linda presented in the first paper of the day where she presented at least some indirect evidence that coho fry may actually avoid this stuff. First, they initially avoided it when she first turned it on; second, territoriality broke down, and we heard the activity levels were elevated. Well, if indeed the fish are avoiding this and if the coho fry are emerging earlier because of increased winter temperatures, then perhaps what we're doing is shoving the period of emergence earlier into the hydrograph during a time when the fish might be exposed to more or perhaps higher turbidities due to disintegration of the bank upstream. I'm wondering if perhaps it is not the high flow per se that is leading to premature (not necessarily premature, but earlier out-migration), but maybe its increased exposure to higher levels or more prolonged levels of elevated turbidity. And I'll let anybody respond to that.

Answer *(G. Hartman)*: First off, I think it would be desirable to look differently at the fry response when they're in the early spring period because those fish early in the spring and the summer, in point of fact, go through the fence, with each of those storm events, long before the stream ever gets into a peak freshet situation. One of the interesting observations that we have made is that, if the peak of the freshet is for example at 2:00 on the afternoon of the 12th, the peak of the fish movement may well have taken place the night before. As such, I'm not sure that I would think that they are not responding to sediment or turbidity. However, if we're considering the responses of fish in the wintertime when they're being dislocated from the pools and piles of debris (Peter Tschaplinski and I have dealt with this phenomenon), then I think that the possibility that sediment or turbidity is involved is more likely. When we talk about the movement of fry, I think we should change the terminology from being *"flushed out"* to *moving out* to sea, because we're not certain that they are really being flushed. They may be behaving in such a way that they go ahead of the freshet. In the main sense of the word, they do not go out with the freshet, but before it.

Comment *(C. Scrivener)*: You may remember, from Mr. Tassone's presentation on suspended sediment, that the amount of material coming out in the spring (after the bigger floods of the winter period have already passed) was less material than during the winter. And the levels that we're talking about for these floods are nowhere near the levels that occurred during the work that Tschaplinski and Hartman did on the yearlings in the middle of the winter. These are quite minor floods and so there isn't usually the kind of accompanying sediment load with these floods. The levels in spring are less than those that Linda Berg was dealing with.

Comment *(P. Tschaplinski)*: The yearly movements that one sees in autumn into side-channel sites are more or less coincident with low upstream temperatures and other environmental cues which are apparent at this time. We don't really have a handle on any cause-and-effect relationship with declining temperatures or changing photoperiod. Nevertheless, I think the point that Peter Bisson brought up about the possible role of sediment is a good one. But, I don't think that high-flow conditions and turbidity necessarily are two variables that have to be separated, because one seems to be attendant with the other.

Question *(P. Bisson)*: With respect to your point about the fish showing very high out-migration early in the fall during the first few storms, maybe the hydrologist could help out on this one. It's my impression that, even though the flow might not be all that high in the first few autumn storms, nevertheless, the suspended sediment flow is proportionately tending to be quite high because it's the first time the stream's been flushed, and there may be some interaction there. What I'm trying to do is to tie in changes in the way sediment is routed out at Carnation Creek to destabilization of the channel, where it's been affected by forest harvest, and to ask does that have an effect on fish behavior.

Answer *(G. Hartman)*: (Charlie Scrivener referred to the possibility that early winter storms might carry a relatively heavy sediment load.) I don't think we know exactly what the fish that live in the main stem of the stream and reside in pools and large debris piles may be responding to when they move.

Question *(T. Harding)*: Gordon, just to refresh my memory. In those three treatment areas, where the habitat was greatly modified in a couple of them, what were the numbers of the fish at the end? and Were they similar or were there differences?

Answer *(G. Hartman)*: In the intensive treatment area, sections 6 and 7, where we did our counts, we had three counting sections. The numbers of fish residing in those areas or left in them after early December were far lower than they were in the lower sections of stream where the streamside vegetation was left intact and the large debris was more stable.

Comment *(P. Tschaplinski)*: Perhaps also it should be mentioned that, although there has been some decrease in the debris volumes in certain sections of the stream and that there is less bank cover available for overwintering fish and that although statistical comparisons were not possible (prelogging and post-logging), there were more fish actually using the side-channel habitats in winter than were using the same habitats before logging. But there are only three years of available data to look at for the logging period. So we can really only look at it as kind of a trend. So perhaps the lack of in-stream habitat has been made up by more use of this slough-type, side-tributary habitat in winter.

ASPECTS OF THE POPULATION BIOLOGY OF ESTUARY-REARED AND STREAM-REARED JUVENILE COHO SALMON IN CARNATION CREEK: A SUMMARY OF CURRENT RESEARCH

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V8W 2Y2

ABSTRACT

Juvenile coho salmon inhabit a large number of small coastal streams (e.g., ≤ 20 km long) in northwestern North America. Thousands of newly emerged coho fry emigrate from these streams in spring and early summer each year. In Carnation Creek (Vancouver Island), some of these emigrants inhabit the estuary from March to October-November. Coho inhabit main-channel and side-channel habitats in the uppermost 250 m of the estuary. Coho habitat requirements were identical to those of their stream-dwelling siblings. Most of the coho inhabited low-velocity sites, including deep pools. The largest number of fish in the main channel occurred in areas where mid-stream water velocities at low tide were ≤ 40 cm/s. Little or no water movement occurred in the side channels. Areas preferred by coho contained cover in the form of undercut banks, overhanging vegetation, and large debris (e.g., root masses, fallen trees). Coho occurred in waters ranging in salinity from 0 to 19 °/oo during periods of maximum high tide in summer.

The late-summer (September) populations of estuary coho totalled 1205 and 2453 fry respectively in 1979 and 1980. These numbers comprised respectively 9.1% and 12.1% of the numbers of coho enumerated in Carnation Creek for the 2 years. Coho emigrating to the estuary from the stream showed high rates of survival and growth. May to September survival rates of the spring (March to May) emigrants were respectively 33.9% and 26.0% for 1979 and 1980. These coho rapidly outgrew their stream-dwelling siblings and were 16.1 mm and 18.0 mm larger on the average by mid-to-late September respectively in the same 2 years. On the average, estuary coho grew from 1.8 to 2.3 times more rapidly than stream-dwelling fry on a monthly basis.

Stream fry emigrating into brackish estuaries gradually develop tolerance to waters of midrange salinities (e.g., 15 °/oo) and increase their resistance to high-salinity water (e.g., 30 °/oo) as they grow during summer. This long-term adaptation allows fry to inhabit brackish estuaries efficiently. By autumn, about 50% of the estuarine fry are at least as large as 1-year-old smolts which leave Carnation Creek in spring. Most of these estuary coho disperse seaward into Barkley Sound in autumn with the onset of the first seasonal freshets. These fry are physiologically able to withstand the midsalinity, near-store, surface waters of Barkley Sound in winter. Large numbers of these estuary-reared fry must be marked to investigate the numbers which can potentially return to Carnation Creek to spawn.

INTRODUCTION

Adult coho salmon (*Oncorhynchus kisutch*, Walbaum) are noted to spawn in small coastal streams such as Carnation Creek. For example, coho in British Columbia select approximately 970 of these relatively small streams (Scott and Crossman 1973). Spawning occurs usually from late September to November (but sometimes to March) in shallow, swift water (Hart 1973; Scott and Crossman 1973). Large numbers of eggs are deposited by each female. Egg number varies with size of female, area, and year and has been reported in Washington State to be 5700 eggs/female in fish ≥ 72 cm long (Scott and Crossman 1973). The fecundity of coho in British Columbia waters varies on the average from 2100 to 2789 eggs/female (Scott and Crossman 1973). Despite the observation that egg-to-fry survival rates are highly variable (Crone and Bond 1976; Hartman et al. 1982; Koski 1966; Pritchard 1947) and may be low (e.g., 15% to 26%) (Crone and Bond 1976), thousands more fry emerge from the stream gravels than these small coastal systems can possibly support. Therefore, thousands of fry leave these streams and enter or pass through the estuaries when they "emigrate" each year in spring and early summer (Hartman et al. 1982; Mason 1974).

Movements of fry downstream occur during the period of fry emergence from the gravel and for variable periods of time afterward (Hartman et al. 1982; Mason 1974). In Carnation Creek, fry emerge generally from April to June. Peak numbers emerge during May (Hartman et al. 1982).

The fate of these "downstream emigrants" was completely unknown until recently. It has generally been assumed that emigrant fry are "in excess of the numbers of fish that streams can support" (Chapman 1962, 1965; Mason 1966, 1976; Mason and Chapman 1965); therefore, these fish have frequently been called "surplus" fry (Hartman et al. 1982). All coho fry were thought to perish soon after entering estuaries and other saltwater environments (Mason 1976; Wickett 1951), even though little evidence was obtained to support this notion. Scale analysis suggested that seaward emigrating fry did not contribute to the next generation of adult spawners (Mason 1976; Wickett 1951). However, a recent study in Alaska has shown that coho fry rearing in estuaries contribute substantially to the population of adult spawners and that these adults can be identified from their scales to have been estuarine-reared individuals (Koski 1982, pers. comm.).

Previous to the present work, estuary populations of coho fry have neither been widely recognized nor studied in detail. This work summarizes some of the salient aspects of an intensive study made from 1979 to 1981 of the biology of coho fry rearing in the Carnation Creek estuary. This summary stresses that:

1. Some of the fry which emigrate from coastal streams become established as a population of estuary-resident coho.
2. Estuaries of small coastal streams are sources of large, rapidly-growing juvenile coho.
3. Estuary-reared populations can contribute important numbers of new recruits to the ocean-dwelling, commercially-fished coho populations and can provide significant numbers of adult spawners.

THE STUDY SITE

The lowermost 3 km of Carnation Creek are available to adult coho for spawning and to juvenile coho (fry and yearlings) for rearing habitat (see Hartman et al. 1982 for descriptions of the stream and watershed). Each year, coho populations (juveniles) in Carnation Creek are enumerated (usually 3 times) during spring, summer, and autumn by the Seber-LeCren (1967) removal method as part of the ongoing research at this experimental watershed. Information from these studies is used to determine population numbers, growth rates, and rates of survival (Narver and Andersen 1974; Andersen and Narver 1975; Andersen 1978). In addition, all fry and smolts emigrating from Carnation Creek during spring and summer are enumerated using a permanent weir facility (Narver and Andersen 1974).

Coho fry inhabit the upper part of the Carnation Creek estuary from the beginning of the period of fry emergence in spring (e.g., March-April) to October-November. Their distribution comprises both the main channel of Carnation Creek which flows through the tidal surge zone and side channels which occur on either side of the main stream. The side channels have low-velocity water and frequently are isolated from the main channel at low tide, especially during summer when stream discharge volumes are lowest (e.g., 0.03 m^3/s) (Stockner and Shortreed 1976). When the side channels are isolated, they occur as discrete pools with no water movement.

Including both the main channel and side channels, the total length of the estuary inhabited by coho fry is 490 m. The channels are 8 m wide on the average at low tide, giving a low-tide "total wetted" area that varies roughly between 3400 m^2 to 3900 m^2, depending on discharge volumes from Carnation Creek.

The estuary contains both vertical and horizontal salinity gradients. Coho inhabit the upper part of the estuary where salinities may reach 19 $^{o}/oo$ near the channel bottoms at high tides of 3 m.

COHO POPULATIONS IN THE CARNATION CREEK ESTUARY

Downstream Emigration

Thousands of newly-emerged fry move downstream toward the sea from Carnation Creek each year (Hartman et al. 1982). Investigators have long attempted to determine the cause of this annual "emigration" that has been observed in many streams. Chapman (1962, 1966), Mason (1966, 1969), and Mason and Chapman (1965) maintained that young fry are displaced downstream as an outcome of intraspecific competition for food and space. These authors and Dill (1978) claimed that coho in streams are territorial and aggressively defend space within which they feed. Those coho, unable to maintain feeding territories, were termed "competitively inferior" and must move downstream to find suitable habitat and food.

Au (1972) also thought that so-called "density-dependent" competition for food and space regulated coho numbers in streams, but not during spring and early summer when thousands of fry are moving downstream. He presented evidence that fry were displaced physically from streams by the action of rapid currents. He thus called these seasonal movements the "early dispersal and colonization phase" because physical dispersal by stochastic processes would place new fry in suitable habitats along the entire length of streams. Au (1972) believed that coho populations were competition-regulated only after these early movements of large numbers of fry were completed. Hartman et al. (1982) found that the relationship between floods and the rates of downstream emigration was complex. Peaks in numbers emigrating sometimes occurred before peak discharge volumes were recorded, thus, suggesting complex cause-effect relationships.

Observation in Carnation Creek in February to April (1981) provided no evidence for density-dependent causes for the early emigration of fry downstream. In 1981, fry began to emerge from the stream gravel during February. During the first week of emergence, coho in the estuary and in 6 selected sections of Carnation Creek were enumerated visually using snorkel techniques. Fry numbers in no section of Carnation Creek exceeded 0.01 fish/m^2; however, > 300 newly-emerged fry had already entered the estuary at the same time. Only 45 fry were counted in all 6 reaches of Carnation Creek which totalled 212 m in length. Despite these low numbers inhabiting Carnation Creek, coho fry already had moved downstream in large numbers.

Whatever processes cause these displacements, it is clear that not all of the downstream emigrants are lost from the rearing population of coho fry. Some of the fish displaced seaward at Carnation Creek inhabit the estuary during summer (Table 1).

Table 1 compares the numbers of fry emigrating downstream in spring and early summer for 1970 to 1980 with the numbers inhabiting the stream in late summer (late August-September) for the same time period and with the numbers inhabiting the estuary in late summer for 1979 and 1980.

The numbers of fry emigrating from Carnation Creek show extreme between-year variability (expressed by 95% confidence limits) which renders prelogging and during-logging mean movements to be statistically equal ($p > 0.05$). Much less between-year variation occurred in the late-summer populations inhabiting Carnation Creek. Eleven-year mean fry numbers of 12 400 ± 1 821 were recorded. Prelogging and during-logging means were statistically equal. The population of fry inhabiting Carnation Creek in 1980 was unusually high (20 293). This value is the only significant departure from the 11-year mean. The relative between-year constancy in coho population numbers likely reflects the total numbers of fry and yearlings that Carnation Creek can support in summer.

The data also show that significant numbers of downstream emigrants establish themselves in the estuary during summer. Estuary fry were enumerated accurately on a monthly basis using the Seber-LeCren (1967) removal method using both pole-seine nets and electrofishing equipment. From 5285 downstream emigrants in 1979, 1205 fry remained in the estuary in late September. This population comprised 9.1% of the numbers of fry rearing upstream in Carnation Creek. Despite the unusually high numbers of coho inhabiting the stream in 1980, the late-summer estuary population comprised 12.1% of the total numbers in Carnation Creek. Over 5 times more fry emigrated from Carnation Creek in 1980 than in the previous year. Accordingly, the late-summer estuary population more than doubled in size in 1980

Table 1. Mean numbers of coho fry emigrating downstream from Carnation Creek compared with mean numbers of coho juveniles inhabiting the stream from 1970 to 1980. Annual (11-year), prelogging, and during-logging means are given. Fry numbers averaged over the same time periods are given in small numerals. For 1979 and 1980, numbers of emigrant fry are compared with the stream-resident populations and those emigrants which remained to inhabit the estuary in late summer. Mean values and stream and estuary population sizes for 1979 and 1980 are expressed with 95% confidence limits.

	Carnation Creek Stream Population Numbers (Late Summer)	No. of Fry Emigrating From Carnation Creek	Estuary Population Numbers (Late Summer)
Annual mean	13 645 ± 1 983 Fry 12 400 ± 1 821	30 006 ± 19 796	
Prelogging mean (1970 to 1975)	12 469 ± 1 428 Fry 11 393 ± 1 427	44 111 ± 34 652	
During-logging mean (1976 to 1980)	15 057 ± 3 647 Fry 13 608 ± 3 325	15 900 ± 7 807	
1979	14 776 Fry 13 230 ± 93	5 285	1 205 ± 6.1
1980	23 095 Fry 20 293 ± 141.5	27 654	2 453 ± 11.0

compared to 1979. In September 1980, 2453 (± 11) fry were enumerated in the estuary.

Seasonal Population Dynamics

Figure 1 illustrates the seasonal changes in the numbers of juvenile coho inhabiting the estuary from spring to late summer in 1979 and 1980. The major curves for each year were constructed from monthly enumerations of the estuary populations; therefore, the curves illustrate the seasonal survivorship of coho in the estuary. In all months, nearly 100% of the population was comprised of fry. In none of the monthly population estimates were more than 16 yearlings found.

The seasonal pattern of downstream emigration (Fig. 1, lower curves for 1979 and 1980) strongly affected the numbers and rates of survival of the estuary population. In May 1979, > 3960 coho occurred in the estuary. The main period of emigration occurred from late March to early May (Fig. 1, lower curve for 1979). Most of the 5285 emigrants in that year thus entered the estuary as a single-period, large influx of fry. This emigration resulted in an estuary population having a length-frequency distribution that was unimodal and normally distributed throughout the summer (not shown). The population decreased in size rapidly from 3964 to 1465 between May and July (Fig. 1). Numbers then stabilized after this period of adjustment which was caused either by mortality or by emigration of individuals from the estuary to the sea (Fig. 1).

The survival rates of coho in the estuary far exceed those of stream-resident coho in Carnation Creek (Holtby and Hartman, these proceedings). Including the May-to-July period when coho numbers were declining rapidly, the seasonal survival from May to September was 30.4%. This rate becomes about 82% when the July-to-September period is considered. Population numbers were far more stable during the latter months.

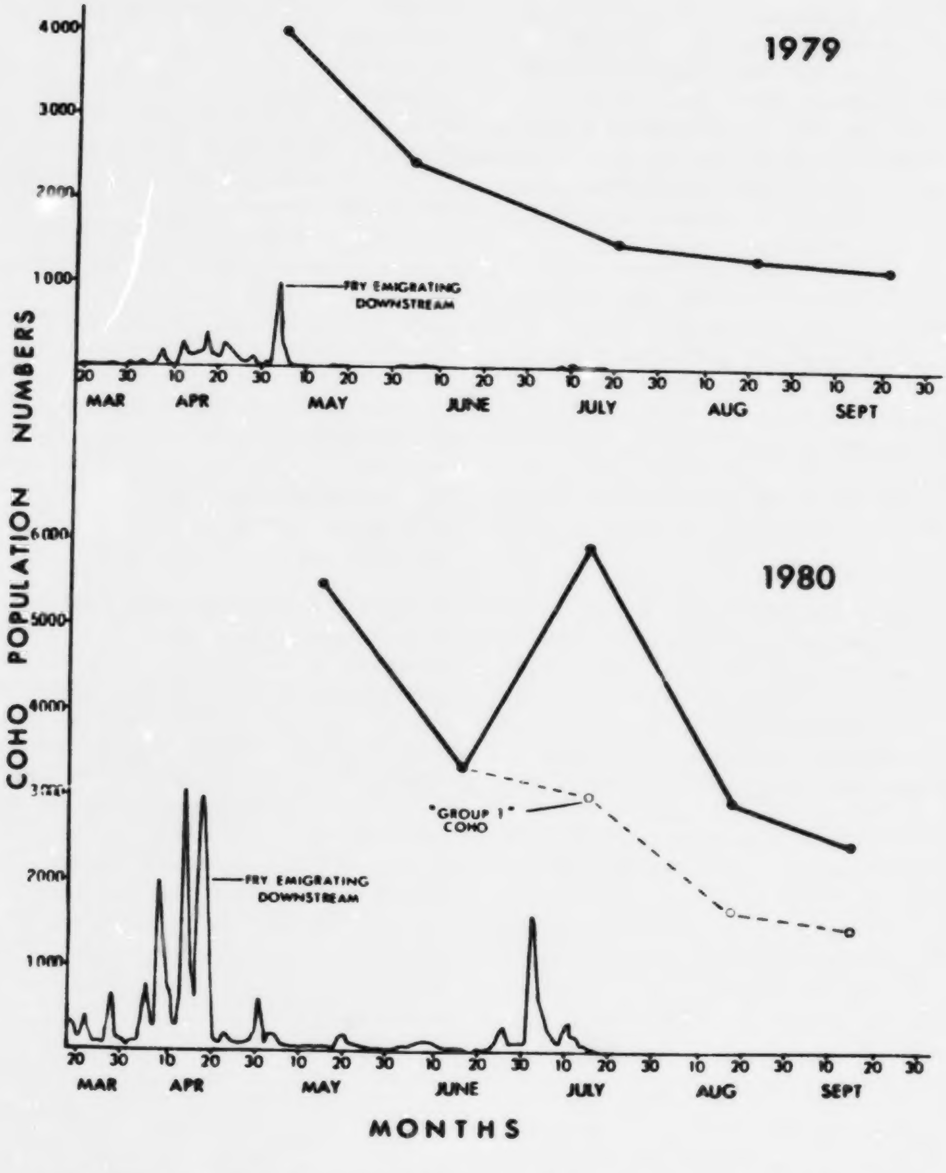

Fig. 1. Seasonal changes in the numbers of coho fry inhabiting the Carnation Creek estuary in 1979 and 1980. The daily numbers of fry emigrating downstream from Carnation Creek are shown by the lower curves for the 2 years. Population numbers are shown by the heavy curves and were drawn from monthly population estimates made by the Seber-LeCren (1967) removal method. The entire populations were enumerated directly each month, except May and June 1979 when selected small sections were enumerated and values were extrapolated for the remaining area. In 1980, 2 major periods of fry emigration produced in July to September a bimodally-sized estuary population comprising (a) original ("Group I") emigrants (dashed line) and (b) smaller-sized, midsummer emigrants ("Group 2" coho). The numbers of the latter group (July to September) are equal to the difference between the total population numbers (solid line) and the numbers of large-sized Group I fry. For all population estimates, 95% confidence limits were < ± 11 fry.

In contrast to 1979, 2 periods of fry emigration from the stream to the estuary occurred in 1980 (Fig. 1). The typical early-spring influx occurred from March to May and resulted in 5451 fry, enumerated in the estuary in mid-May (Fig. 1). Population numbers declined rapidly as in the previous year and fell to 3337 fry in June. It is assumed that population numbers were determined by the available resources of space and food in the estuary.

However, a second major influx of emigrants from Carnation Creek occurred in midsummer (Fig. 1; late June and July). This additional emigration, not occurring the previous year, was due to a storm which produced very high discharge volumes in Carnation Creek. The population curve (Fig. 1, 1980) shows that the estuary was able to accommodate initially many of the > 5000 new emigrants that were displaced downstream. Thus, in mid-July, the fry population rose to 5898.

The new emigrants (called "Group II" fry) were much smaller in average size (length and weight) than the original emigrants from Carnation Creek (called "Group I" fry). The 2 groups of coho were readily separated, both numerically and by size, using the probability-distribution methods of length-frequency analysis (Cassie 1954; Harding 1949). Accordingly, 2 population survivorship curves are given for the estuarine coho from July to September in 1980 (Fig. 1). Both "Group I" and "Group II" (new fry) are distinguished in Fig. 1. The 1980 population was bimodal in size-frequency due to the presence of two temporally separated emigrations. The growth rates, numbers, and survival of each normally distributed size mode of fry were easily determined for the entire season.

The mean size (length) of the original (Group I) estuary residents was 58.3 mm ± 0.1 mm (95% confidence limits) in July, whereas that of the new (Group II) emigrants was only 42.2 mm ± 0.1 mm. This size difference suggests that fry inhabiting the estuary grow more rapidly than their stream-resident siblings. Given the observation that downstream emigrants may be slightly smaller in mean size (e.g., 1 mm to 3 mm shorter) than fish which remain upstream (Chapman 1962; Mason 1966, 1969, and later discussion in this work), it is possible that differences in size between estuarine and stream fry may be thus biased towards showing increased differences in growth rate. However, the differences in average size between the "Group I" and "Group II" fry were large (16.1 mm) and suggest strongly that estuarine fry rapidly outgrow stream-resident coho.

The influx of additional fry in the midsummer of 1980 resulted in other changes in the dynamics of the estuary population. The period of numerical decline in the population as a whole was prolonged until August by the input of new fish (Fig. 1). The "mortality" ("disappearance") rate of the new emigrants was especially high. From July to September, only 33.9% of the Group II fry survived in the estuary; the survival rate of the Group I coho was significantly higher at 47.3% over the same period. Even though this July-to-September survival rate for the original residents was > 57% lower than that observed for estuary coho in 1979 (July to September), the seasonal survival rate (May to September) of 26.0% compares favorably with the seasonal rate of 30.4% achieved by estuary coho for 1979 (May to September).

Despite the facts that (1) the initial (May) population numbers were much higher in 1980 than in 1979 and (2) the midsummer (July) numbers were more than 4 times higher, the larger 1980 population did not markedly reduce the survival of Group I (original) estuary fry. These large-sized, prior-resident fry may have outcompeted many of the later, smaller emigrants for available food and space and thus achieved a higher survival rate than the latter coho. However, it is clear the estuary was still able to accommodate large numbers of new coho displaced from upstream habitats due to catastrophic events (e.g., floods). The estuary thus provided additional or "reserve" habitats to such displaced coho (individuals that might otherwise be lost to the rearing population of the Carnation Creek system).

Distribution of Coho
In the Estuary

The characteristics of the physical habitats in Carnation Creek and its estuary differ in several ways. Even for a small stream such as Carnation Creek, the total "wetted" area of the tidal portion can be large (varying between 3400 m^2 to 3900 m^2). Much of this area is unsuitable for coho fry to inhabit; therefore, the overall coho numbers per square metre ("densities") are lower on the average than those found in Carnation Creek (Table 2).

Table 2 illustrates the late-summer densities of coho in Carnation Creek and its estuary relative to total surface ("wetted") area and to area of pool habitat.

Table 2. Late summer coho numbers per square metre in Carnation Creek and its estuary in 1979 and 1980. Values are given relative to total surface ("wetted") area and area of pool habitat. The stream and the estuary were subdivided into separate sections to enumerate coho populations. The ranges about each overall "density" value reflect the maximum and minimum numbers per square metre determined among the study sections. Annual (11-year) mean densities and mean values for prelogging and during-logging periods are also included together with 95% confidence limits.

	Coho Fry Densities (Late Summer)			
	Numbers/m^2 Wetted Area		Numbers/m^2 Pool Area	
1979				
– Estuary	0.31	0.08 to 0.79	0.45	0.11 to 1.17
– Stream	0.74	0.29 to 1.14	0.92	0.39 to 1.51
1980				
– Estuary	0.75	0.15 to 1.79	1.05	0.20 to 1.89
– Stream	1.26	0.70 to 1.97	1.60	0.70 to 3.00
Stream				
– 11-year mean	0.81	± 0.14	1.02	± 0.31
– Prelogging	0.87	± 0.12	1.08	± 0.29
– During-logging	0.74	± 0.24	0.95	± 0.33

Comparatively low numbers of coho inhabited the estuary in 1979 (Table 1); consequently, the mean overall numbers per square metre were less than one-half the numbers per square metre averaged for several sections in Carnation Creek (Table 2). Similarly, estuarine coho densities in 1980 were lower than those determined for the stream population. However, the 1980 coho population in Carnation Creek was unusually large (Table 1). When the coho numbers per square metre for the estuary in 1980 are compared to either the (a) 11-year, (b) prelogging, or (c) during-logging mean values for Carnation Creek, the estuary densities fall within these means (Table 2).

The estuary was divided lengthwise into 10 sections to capture and enumerate fry conveniently. Several sections differed in physical habitat characteristics. The numbers of coho per square metre were determined in each section and the highest and lowest values comprise the range about each value for overall coho density given in Table 2.

Table 2 shows clearly that the ranges about the mean fry densities are extreme and illustrate that coho are distributed irregularly in the estuary. In different estuary sections, densities ranged from 0.08 to 1.79 fry/m^2 (wetted area) and 0.11 to 1.89 fry/m^2 (pool area).

High concentrations of fry (e.g., 1.89/m^2 in late summer) were found in (1) main-channel reaches of low water velocity ($\leq$ 40 cm/s) having ample cover provided by deep pools (e.g., $\geq$ 45 cm deep), undercut banks, and masses of large debris (logs, fallen trees) and (2) side channels with little or no water movement and having shelter in the form of undercut banks with overhanging vegetation (shrubs, grasses, sedges). In May when populations are large, such sites supported up to 4.09 coho/m^2 (pool area).

The spatial requirements for coho inhabiting estuaries are identical to those of their stream-rearing siblings (Hartman 1965). Low-velocity habitats (e.g., pools), containing cover in the various forms described, are essential to coho occupying both environments. Coho fry do not undergo shifts in their habitat requirements when they move from streams to estuaries in spring and summer.

Space thus seems to be the main factor limiting the numbers of coho inhabiting the Carnation Creek estuary. Very low numbers of fry (e.g., 0.08/m^2 pool area) occur in reaches containing broad (8 m to 15 m), open areas of relatively shallow, rapidly-flowing water (> 50 cm/s) having little cover provided by banks, overhanging vegetation, or large debris.

About 200 m of estuary occurred downstream of the part of the tidal region occupied by coho fry. Coho did not occur in this lower (outer) portion of the estuary which was characterized by a wide, shallow channel containing no cover. This part of the estuary contained no habitats suitable for coho. Salinities during high tide in the outer estuary were somewhat higher than the 19 to 20 $^{o}/oo$ values observed at the channel bottom in the upper reaches occupied by coho. However, high-tide salinities never exceeded 25 $^{o}/oo$ near the channel bottom in the outer estuary during summer. The distribution of coho in the Carnation Creek estuary was thus concluded to be limited mainly by available habitat space and to a lesser degree by higher salinities (see later discussion of salinity tolerance of coho fry).

Comparative Seasonal Growth
Between Estuary and Stream Coho

Figure 2 and Table 3 compare respectively the mean monthly sizes and monthly growth increments of coho fry inhabiting Carnation Creek and its estuary. In early spring (April), stream and estuary siblings are very close to the same size (Fig. 2). Accurate determinations of mean fish size in early spring is difficult in reference to true determinations of growth because large numbers of new, small-size fry emerge daily during April and May. True determinations of growth rates are impossible, unless fish are marked individually for identification. During early spring (especially in 1979), mean fish sizes were calculated from small samples (e.g., N < 200) collected from the stream and estuary populations and from downstream emigrants enumerated at the Carnation Creek main weir.

The first clear differences in growth rates between stream-reared and estuarine coho are discernible in May (Fig. 2 and Table 3). From June to September, the estuary coho rapidly outgrew stream-dwelling fry. The mean size (length) of estuary juveniles increased until the fry became 16.1 mm and 18.0 mm larger than stream coho by mid-to-late September in 1979 and 1980 respectively. Growth rates of downstream emigrant coho therefore increase and exceed the rates of stream-dwelling coho after these emigrants enter estuaries, regardless of the initial size of the emigrant fry in spring. By autumn, about 50% of the fry which inhabited the estuary from April-May to September are at least as large as the 1-year-old smolts leaving Carnation Creek for the sea in spring.

In 1980, coho fry grew at rates identical to those occurring in 1979, even though the estuary population had more than doubled in size. Coho were clearly not food-limited in the estuary, even at these higher numbers (which occurred in the same total area as in 1979).

Table 3 illustrates and compares monthly growth increments between stream and estuary coho. In 1979 and 1980, estuary fry grew respectively 1.8 and 2.3 times faster than their stream-dwelling siblings on a mean monthly basis. These trends are consistent when the growth rates of estuary fry are compared to mean monthly growth increments of coho in Carnation Creek that were averaged over 10 years (Table 3).

The growth of estuary coho illustrated in Figure 2 and Table 3 for 1980 includes only the original (Group I) emigrants which entered the estuary in the spring. The later (midsummer) emigrants were not included in those calculations. The population curves in Figure 1 show that these Group II coho survived in lower numbers (about 34%) than the original group; however, those midsummer emigrants which were able to find suitable habitat survived and grew as rapidly as the larger Group I individuals. Between July and September, the smaller Group II coho increased their mean length from 42.2 mm (± 0.1 mm, 95% ci) to 54.4 mm (± 0.1 mm), a total change in length of 12.2 mm.

In July 1980, the late-emigrating fry were > 16 mm smaller on the average than the spring emigrants. Because of the great differences in body size between the two groups of coho in the estuary, the population was heterogeneous and covered a broad range in sizes. For example, fry in August ranged in body length from 39 mm to 84 mm.

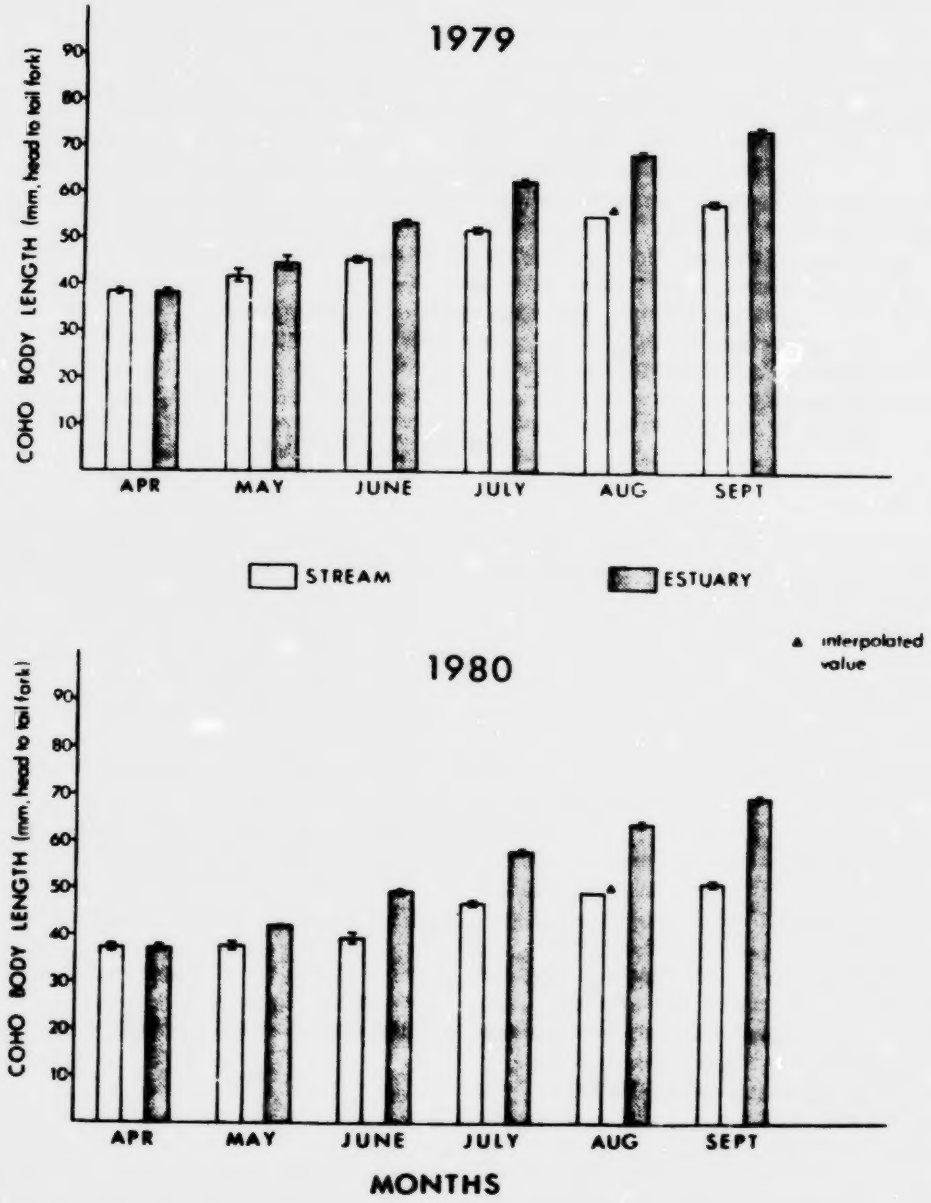

Fig. 2. Comparative seasonal growth in stream-dwelling and estuarine coho fry. Growth is illustrated by monthly mean lengths (mm) of coho collected from the two environments. For 1980, growth in estuary coho is shown only for "Group I" fry (see text). All values are given with 95% confidence limits, except for stream fry in August 1979 and 1980 when no data were available. Values for the latter period were interpolated between those of July and September. Mean sizes for stream fry for April-May 1979 and April to June 1980 were determined from small samples collected randomly from Carnation Creek (N < 200 for each month). All other mean values were determined from large samples of coho measured when populations were enumerated.

Table 3. Comparative monthly growth increments between stream-dwelling and estuarine fry. Mean monthly growth increments and total seasonal growth for stream and estuary fry are included for 1979 and 1980 and are compared to annual (10-year) mean values for coho populations in Carnation Creek. For 1980, growth is shown only for the "Group I" (original) estuary residents (see text). Mean monthly growth and annual mean values for Carnation Creek are given with ranges. Interpolated values are given for July-August and August-September intervals for stream coho (see explanation, Fig. 2). All growth values between stream and estuary coho were significantly different ($P < 0.05$, Wilcoxon paired-sample test).

	Comparative Monthly Growth Increments (mm)			
	1979		1980	
	Stream	Estuary	Stream	Estuary
April				
Δ	3.5	6.3	0.5	4.6
May				
Δ	4.2	8.8	1.9	7.6
June				
Δ	5.8	9.2	7.2	8.5
July				
Δ	3.1▲	6.2	2.3▲	6.0
August				
Δ	3.2▲	5.4	2.2▲	5.4
September				
Mean	4.0	7.2	2.8	6.4
Total Growth	19.8	35.9	14.1	32.1

Carnation Creek (1971 to 1980):

— Mean monthly summer growth = 2.9 (0.3 to 8.3)

— Mean total season growth = 16.0 (8.0 to 21.7)

▲ interpolated value

This broad size-frequency distribution minimizes intraspecific competition among estuary coho, for example, for the same food resources. Efficient food-resource partitioning among different size-classes of coho can occur through size-selective predation. Such mechanisms result in rapid growth in all size-classes of coho (discussed in a later work).

Physiological Adaptation of Coho Fry to Estuarine Environments

Introduction

Typically, fry must remain at least 1 year in streams before emigrating (usually during spring and early summer) seaward as smolts. The transformation of freshwater fry into smolts is a complex process involving morphological, behavioral, and physiological changes (Hoar 1976; Vanstone and Markert 1968). Prior to this work, one of the main arguments against the notion that coho fry inhabit estuaries successfully involved the question of the physiological ability of coho fry to survive and grow in saline waters. Laboratory tests have shown that coho juveniles (alevins and fry) survive poorly in high salinity water (e.g., about 32 $^{o}/oo$) before they achieve the smolt life stage (Weisbart 1968). Clarke et al. (1978), Clarke and Negahama (1977), and Kennedy et al. (1976) observed that coho fry which survived in seawater grew poorly. Poor growth was correlated with the inability of fry to osmoregulate in high-salinity water. Unlike smolts, fry could not maintain their plasma sodium (Na^+) concentrations at or below 170 mM (Clarke and Blackburn 1978; Clarke et al. 1978; Clarke and Nagahama 1977). Within 24 h, the plasma sodium ion concentrations of the intercellular fluid increased and exceeded 200 mM and became lethal in many fry.

However, such laboratory tests of salinity tolerance using high-salinity water are not relevant to coho fry inhabiting brackish estuaries where salinities vary widely. For example, Clarke and Blackburn (1978) found that coho fry survive and grow well in the laboratory in 20 $^{o}/oo$ brackish water. Conte et al. (1966) demonstrated clearly that coho fry in the laboratory could survive and grow in water of intermediate-range salinity. Furthermore, Otto (1971) showed that the tolerance of juvenile coho to high-salinity water was increased by a 35-day exposure to water of relatively low salinity. His fry achieved their highest growth rates, food consumption, and growth efficiencies when they were kept in water of 5 to 10 $^{o}/oo$ throughout the fry-to-smolt period. Otto (1971) thus demonstrated that tolerance to saline water in coho fry can occur before the smolt transformation and is partly independent of that process. His results suggest that coho fry may adapt gradually to waters of progressively higher salinities after they enter estuaries.

Fry in the Carnation Creek estuary were sampled on a monthly basis from July to October-November to determine (1) if fry were seasonally developing increased salinity resistance (e.g., to high-salinity water), (2) if fry were able to osmoregulate in middle-range salinities during their summer period of rapid growth, and (3) if estuary and stream-dwelling siblings collected at the same time showed differences in tolerance to waters of different salinities.

Methods

Samples of coho fry of the same mean body length were collected monthly from Carnation Creek and the estuary (see Fig. 3 for sizes of fish used). Fry were transported immediately to the laboratory and allowed to acclimate in fresh water in 189-litre tanks at 15°C for 24 h before experiments were conducted. Fry from the Goldstream River estuary (Vancouver Island) were used in October-November due to the low numbers inhabiting the Carnation Creek system at that time of year.

In order to regulate thier ionic composition, coho juveniles in saline water must activate the so-called "chloride cells" of the gill tissues (Hoar 1976; Vanstone and Markert 1968). These cells effect ion movements actively with the external environment (Hoar 1976). To determine if such regulation is occurring, short-term exposure (for example, for 24 h) of coho to high-salinity water is sufficient (Clarke and Blackburn 1977, 1978). Longer tests (e.g., 72 h) are convenient when fry are examined in water of midrange salinity in order to achieve consistent, reproducible values for plasma ion concentrations.

To examine both long-term (in reference to monthly collection fry) and short-term (e.g., acute, 24-hour tests) salinity adaptation, groups of estuary and stream fry were then placed into different 189-litre tanks containing (a) freshwater, (b) 15 $^{o}/oo$ (mid-range) brackish water, and (c) 30 $^{o}/oo$ (high-salinity) seawater respectively for 24, 72, and 24 h at 15°C. Ten fry from both the stream and the estuary were used for each of the 3 tests each month. The temperature chosen approximates closely the mean diurnal maximum temperatures in both Carnation

Creek and its estuary in summer and is also a temperature at which coho growth efficiencies are maximum (Averett 1969).

After the appropriate time period, each fish was removed from the experimental tanks and anesthetized with a 1:4000 aqueous solution of 2-phenoxyethanol. An aliquot of blood was taken from the caudal artery using heparinized microcapillary tubes. A 2 - µL aliquot of centrifuged plasma was eventually prepared for analysis. The degree of osmoregulation was determined by measuring the plasma concentrations of the sodium ion (Na^+) by flame-emission spectrophotometry (Clark and Blackburn 1977, 1978). Techniques and methods of analysis employed followed those of Clarke and Blackburn (1977, 1978). Fish in fresh water served as "controls" to determine baseline values for solutes in the intercellular body fluids (blood).

Results and Discussion

Control fry (freshwater test) from both the stream and the estuary maintained their plasma sodium concentrations below 170 mM throughout the summer growing period (Fig. 3). These concentrations are the same as those of osmoregulating smolts living in high-salinity seawater. In no month did the stream and estuary fry differ significantly ($p < 0.05$) in their plasma sodium concentrations. Both groups of fry osmoregulated consistently at the same levels in the hypoosmotic medium. However, estuary and stream fry showed marked seasonal differences in their ability to control their plasma Na^+ concentrations in both brackish and high-salinity water (Fig. 3).

In midsummer (July), stream and estuary fry kept for 72 h in 15 °/oo brackish water did not differ significantly ($p > 0.05$) in their plasma Na^+ concentrations. Nevertheless, the estuary fry did show a trend toward lower concentrations. Even though both groups of fry maintained their plasma Na^+ levels above 170 mM, the concentrations of sodium ion in their plasma was only slightly higher on the average (Fig. 3). These plasma ion concentrations were not lethal and did not impair in any way the feeding frequency or activity levels (swimming ability) of the fry.

From August to October-November, estuary-dwelling fry maintained their plasma Na^+ concentrations at or below the 170 mM level (Fig. 3) and thus were able to osmoregulate completely in the midsalinity water of the estuary for most of the summer and during autumn. In contrast, stream fry not previously exposed to saline water were unable to achieve similarly low plasma Na^+ levels. The plasma Na^+ concentrations of stream coho remained nearly the same as the July value throughout the experimental period (Fig. 3).

These results demonstrate that: (1) regardless of the size of the fish, complete adaptation to brackish water in presmolt estuary coho is a long-term (gradual) process occurring midway during the first summer of growth; (2) short-term adaptation is not possible as shown for stream fry immersed for 72 h in 15 °/oo water from July to early November; and (3) stream fry displaced into estuaries at any time in summer are able to withstand brackish water without lethal effects (no mortality was observed) but then require a long-term period (e.g., > 30 d; Otto 1971) to adapt fully to the salinity regime of the upper estuary.

Similar differences were demonstrated by stream and estuarine coho immersed in acute tests for 24 h in 30 °/oo (high-salinity) water (Fig. 3). Regardless of body size, stream fry were unable to osmoregulate and demonstrated plasma Na^+ concentrations > 200 mM throughout the season. Therefore, no short-term adaptation to high-salinity water occurred. Mortality occasionally occurred among these stream fish. Estuarine fry were able to maintain significantly lower plasma Na^+ levels from August to October-November; however, concentrations of Na^+ were always > 180 mM (Fig. 3). At no time during the experimental period were the estuary fry able to osmoregulate fully in 30 °/oo seawater. Despite the fact that their plasma Na^+ concentrations were > 180 mM, swimming and feeding activity in estuary-reared fry appeared unchanged from the controls, and lethal plasma Na^+ concentrations were never reached.

The data in Figure 3 show clearly that coho fry are able to enter estuaries, survive, and adapt gradually to brackish water as they grow. It is known that salinity adaptation during the smolt transformation is correlated strongly with growth rate and is stimulated by pituitary growth hormone (Clarke et al. 1977; Clarke and Nagahama 1977; Komourdjian et al. 1976). Clarke and Blackburn (1978) documented that the ability of coho fry to osmoregulate increases markedly as the fish grow to smolt size. In fact, Garrison (1965, 1971) raised coho fry in brackish ponds and found that the fish grew rapidly and became smolts in their first year (in about 90 d). Similarly, Heard (1976) reared fry from Sashin Creek (Alaska) in estuarine pens and discovered that (1) coho fry grew rapidly, (2) fry tranformed into

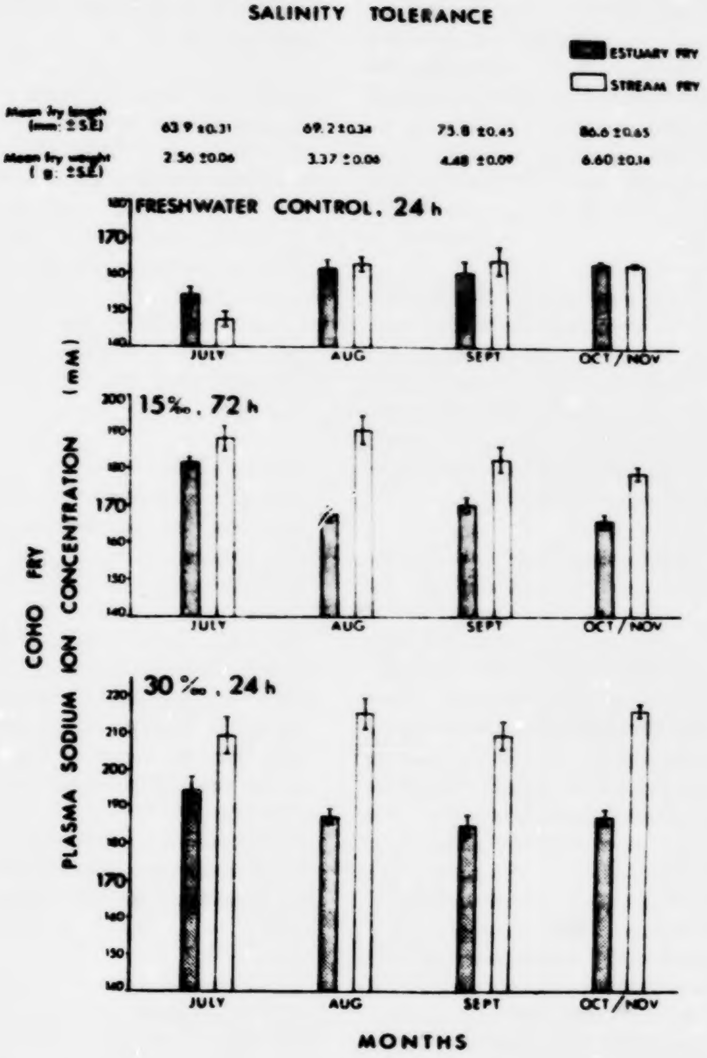

Fig. 3. Seasonal salinity tolerance in stream-dwelling and estuarine coho fry. Ten fry each from the stream and the estuary were used each month for each of the 3 experimental groups noted. The degree of salinity tolerance is measured by the sodium ion concentration of the blood plasma. Estuary fry from the Goldstream River (Vancouver Island) were used for the October-November sample.

smolts normally, and (3) 2 groups of released smolts completed a normal oceanic life and returned as spawning adults in numbers proportional to the sizes of the released groups. Heard (1976) speculated that the higher growth rates of fry in estuaries might be due partly to warm temperatures and to decreased metabolic costs of osmoregulation in brackish waters compared to fresh water. The rapid growth of estuary coho is a positive stimulus for these fish to increase their salinity tolerance through physiological adaptation (see Hoar 1976).

During summer, rapidly growing fry in the Carnation Creek estuary gradually shift their distribution to increasingly saline waters at high tide (e.g., water of 19 to 20 °/oo). This shift allows fry to occur lower in the water column at high tide as the season progresses (since saline water is more dense than fresh water). Benthic feeding on prey temporally abundant at high tide can then occur (discussed in a later work).

In autumn (e.g., October-November), coho fry disperse from the Carnation Creek estuary. Few fish remain and few return to the lower reaches of Carnation Creek and its tributary Dick Creek. Most leave the estuary by emigrating seaward with the onset of the first seasonal freshets. In Porcupine Creek, Alaska, roughly 60% of estuary-reared fry return upstream to overwinter before leaving for the open ocean in the following spring (Koski 1982, pers. comm.). The remaining 40% leave Porcupine Creek for the sea in autumn. Both fractions contribute to the population of spawning adults which eventually return to the system (Koski 1982, pers. comm.).

Although the smolt-sized fry leaving Carnation Creek in autumn are shown not to fully osmoregulate at 30 °/oo, other tests demonstrated that coho fry were able to maintain plasma Na^+ concentrations in water at 26 °/oo (not shown in Fig. 3) that were statistically equal to levels of Na^+ measured in fish kept in 15 °/oo water. It is therefore concluded that coho fry leaving the estuary in autumn are readily able to physiologically tolerate the brackish conditions of near-shore surface waters of, for example, Barkley Sound in winter.

GENERAL SUMMARY AND DISCUSSION

About 300 large estuarine fry were "nose-tagged" with coded wire in late autumn 1981 to investigate the numbers which might return as adult spawners. In the future, much larger numbers must be tagged to ensure better chances of recapture. Returns are awaited.

There are several biological and management implications of the use of estuaries as rearing habitat by coho fry. In terms of habitat protection and enhancement, the spatial requirements of coho fry are clear. Fry prefer channels with cover provided by large debris (e.g., fallen trees), undercut banks, and overhanging vegetation. Young coho require low-velocity microhabitats. For example, midchannel water velocities ≤ 40 cm/s are sufficient. Deep pools comprise preferred habitat, but slow-moving water varying from 5 cm to 200 cm deep at low tide is sufficient.

Estuary coho are able to prey efficiently on the abundant invertebrate food organisms in estuaries, especially "marine" benthic species (e.g., *Corophium*, *Eogammarus*, *Neomysis*, and several others in the Carnation Creek estuary). Coho prefer small estuaries (e.g., Carnation Creek, Goldstream River, Porcupine Creek) because the sheltered habitats they require are usually present in small systems. Given the fact that numerous sites occur along the northwest coast of North America, small estuaries may provide important numbers of coho smolts to the entire population. Obviously, practices which may destroy or alter estuarine habitats such as log booming and the input of large amounts of small-sized, logging-caused debris (e.g., wood chips) or gravel from streams should be avoided or minimized.

Coho population processes in estuaries are relatively unaffected by events occurring upstream. This work has shown that estuary fry have rates of growth and survival that are independent of those of stream fry. Neither the numbers nor the biomass of estuary coho are affected directly by processes occurring upstream. Regardless of any catastrophic event occurring upstream which causes fish to be displaced into estuaries, the tidal areas of such streams can thus function to provide large, fast-growing fry which can conserve the spawning run of adults, despite low numbers of smolts occasionally produced upstream.

Therefore, in a heavily exploited commercial population such as coho salmon, the recruitment of large numbers of large-sized, rapidly-growing fry from estuaries is important to:

1. Maintain the commercially-fished stock through "recruitment" (Ricker 1975) and thus contribute to the "stock density" of the fishery (Ricker 1975).

2. Conservation of the ocean-dwelling populations (by recruitment which provides new adults to the population regardless of habitat destruction in streams which causes coho to be displaced into estuaries).

3. Contribute individuals to the population of adult spawners (large, fast-growing fish of supposed high ecological "fitness").

4. Increase the effective reproductive potential of spawning females—not all young coho displaced from streams (e.g., by intraspecific competition, floods, or other causes) are lost to the rearing population.

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QUESTIONS TO P.J. TSCHAPLINSKI

Question *(R. Murray)*: I have a question for Peter Tschaplinski. Regarding coho in the estuary, What proportion of the juvenile productivity would these fish comprise?

Answer *(P. Tschaplinski)*: I haven't gotten to productivity calculations yet. And in terms of numbers, roughly 9% to 12% of the numbers that are rearing upstream are found in the estuary. Proportionately, they should be reflected in the biomass as well. And you know it's a figure that can be very easily derived, but I have just not determined the production figures as yet.

Comment *(R. Murray)*: I was thinking that, given the larger size of those fish, if they were a significant part of it, any change in coho production from the stream would be partially masked by the productivity in the estuary.

Comment *(P. Tschaplinski)*: That's a fair assumption and it underlies one of the properties that the estuary population does possess: that is, what goes on in the estuary (as shown by graphs on the actual population statistics throughout the summer) are events that are relatively unaffected by those events upstream. The estuary population is very important in the management aspect because, no matter what happens upstream, you may still have a number of fish in the estuary that could very rapidly reach a large size and would enter the sea many months in advance of those fish which are reared in the stream. However, it is not known in what form those fish return to the stream. Many people tell me they don't think they come back at all; so this is another thing we have to look at.

Question *(T. Northcote)*: I want to know, Is there any evidence from the adult scale characteristic, chemically, or the analysis of otoliths, that indicates the early estuary life stage?

Answer *(P. Tschaplinski)*: There's no evidence for that whatsoever. The big question about the significance of the estuary population, and the biggest criticism I get, is that we just don't see evidence of estuary rearing in the scales of the fish that return to the stream. However, we must determine what the scale of the estuary fish is going to look like compared to the scale of the stream fish. Throughout the whole summer period of rearing, I can't tell the difference between the scales of the estuary fish and the stream fish, other than noting that the circuli of the estuary fish are set wider apart. We have to make some assumptions about where these fish go in the autumn, what they feed on, and what their total growth is during this period to be able to set a standard for measuring what their scales would look like if or when they come back as adults.

Comment *(T. Northcote)*: But there are other ways of checking this than just looking at the scales. You could do chemical analysis of the central part of the scale. You could also check the early growth as shown by daily rings.

Answer *(P. Tschaplinski)*: I certainly haven't done that and I know of no field investigations that did it.

Question *(D. Narver)*: Peter, you just said you expected that these fish, these so-called nomad migrants, moved into the estuary and actually entered the ocean months ahead of the stream-resident type. So you're assuming that they don't overwinter in that area and go on as true smolts the next spring. They, in fact, go out some time that first year?

Answer *(P. Tschaplinski)*: You certainly don't see them in the estuary in late autumn, and the time of their disappearance depends on the distribution of freshets in a system. They sort of respond to freshets much as do the stream fish. They just are not found in the main channels; they're not even found in side channels of the estuaries. Small numbers of fish can be seen throughout the early winter months, but certainly the numbers are very low. And there's no real return to the lowermost portions of Carnation Creek or even Dick Creek. I've looked through those sections quite thoroughly in winter and the fish are just not there. So I assume they are either in nearshore waters or the surface waters of Barkley Sound during that period.

Question *(D. Narver)*: But nonetheless, whatever happened to the tens of thousands of fry that were marked by hand in 1972 or 1973 or near that time? Did any of these come back?

Answer *(R. Ptolemy)*: In 1972, I was out there from May 1 onward through to late July. I marked 16 000 coho fry which were classed as nomadic fry passing downstream at the main fence. The subsequent low recovery of those marked fish the following year and second year would indicate that the percent of marked fish was rather small. However, I am not too sure that there was a lot of effort made to look for these fish as adults. The results are not really conclusive.

Comment *(P. Tschaplinski)*: I think it's very important to consider the time of year that you do mark fish that go through the system. If, in fact, you mark many thousands of fry that go through the downstream counting fence in spring, only a very small proportion of those fish may actually take up residence in the estuary. I think perhaps it would be more productive to work with fish that have been in the estuary during the summer to mark them in the autumn and to look at returns from such marks because, in early spring, coho fry are somewhere around 35 mm to 40 mm long. Once these fish are introduced directly to the waters of Barkley Sound, I'm very pessimistic about their survival because there is plenty of information that suggests that, at this very small size, fish that don't manage to establish in the estuary fare very poorly in saline waters. Not only are they unable to osmoregulate but also they are very poor swimmers at this stage and the predation on these fish in a system like Barkley Sound must be fairly high. After all, they are very heavily parr-marked, and it's kind of like wearing a billboard saying "shoot me".

Comment *(K. Koski)*: My name is K. Koski, I'm with the Auke Bay Laboratory and I'd just like to comment on Peter's work. We had a similar situation in southeastern Alaska. Our stream has an area comparable to your estuary which we call the stream estuary ecotone, for lack of a better word. It extends about 1500 m and it makes up about 20% of our entire rearing area. The stream in this area is also very similar in that a large number of fry move to the estuary in the spring and summer and live at probably twice the rearing density with an exceptionally high growth rate. The food production there is tremendously high; amphipod and isopod communities are up to 100 000 organisms per square metre. The fish leaving that area leave it in the fall, and we think a lot of them go back upstream over winter. However, we have evidence that there are a large number of these fish leaving and going out into the actual estuary, perhaps as smolts, in the fall. Now we have a real discrepancy in our smolt count. We're off about 50% on our smolt count for the spring, indicating there could be a fairly significant fall smolt movement out of our system. And there is some evidence in Alaska that there are some systems where fall smolts have returned. We have looked at scales and there is a definite scale pattern on these stream ecotone fish. And I have a graduate working for me who is finishing a master's thesis and his sole purpose is looking at scale characteristics. Those scales do have a different pattern, the circuli are wider. He has been able to look at some of our adult returns and he believes that a few of these fish are ecotone-produced fish. Our stream-ecotone area is a big area and it makes a big contribution to the total rearing production of the stream.

THE POPULATION DYNAMICS OF COHO SALMON (*ONCORHYNCHUS KISUTCH*) IN A WEST COAST RAIN FOREST STREAM SUBJECTED TO LOGGING

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INTRODUCTION

Carnation Creek is typical of small, low-gradient streams on the west coast of Vancouver Island. Such streams are important for both their salmonid and forestry resources. The management of multiple resources within a single watershed demands an understanding of how any one resource is likely to be affected by perturbations associated with the exploitation of the other resources. In the case of a small watershed like Carnation Creek, it would be advantageous to understand how the population dynamics of stream salmonids are affected by changes in the stream associated with forest harvest.

In the analyses reported herein, we have attempted to identify the factors which regulate the in-stream population dynamics of coho salmon (*Oncorhynchus kisutch*). With an understanding of the processes through which watershed disturbances impact stream salmonids, the findings of the Carnation Creek study can hopefully be usefully applied elsewhere to improve the joint management of the salmon and forestry resources.

Study Area

The Carnation Creek study area is thoroughly described elsewhere (Oswald 1973; Scrivener 1975; Bustard and Narver 1975). Detailed descriptions of the soils, vegetation, and hydrology of the study site are provided by Oswald; King and Oswald; Hetherington; Hartman and Holtby; and Scrivener and Anderson, all in these proceedings.

Anadromous fish utilize the lower 3.1 km of the stream. Chum salmon (*Oncorhynchus keta*) spawn in the lower 200 m of the stream. Coho salmon (*O. kisutch*) utilize all of the accessible stream. Resident cutthroat trout (*Salmo clarki*) are found above the impossible falls at 3.1 km. Small numbers of steelhead (*S. gairdneri*), sea-run cutthroat trout, and pink salmon (*O. gorbuscha*) spawn in the main channel. Coast range sculpin (*Cottus aleuticus*) and prickly sculpin (*C. asper*) also occur in the lower main stem.

METHODS

Lengths, weights, and population numbers of coho salmon were obtained from population surveys in four to six study sections. These sections were approximately 100 m in length and were chosen to be typical of habitat available in the creek. Each year, three or more of these surveys were completed: one in late May-early June, one in late July, and one in late September. Unfortunately, streamflow conditions did not permit completion of the surveys on exactly the same dates each year, but over the 11 years reported here, most surveys were done within the 12-day periods of May 17 to 29, July 21 to August 3, and September 12 to 24.

Fish were collected by a combination of pole seining and electrofishing. The wetted area of riffles and pools in each section was measured during each survey. In 1970 and 1971, coho population estimates were determined by mark recapture methods. Later estimates were determined by removal method (Seber and LeCren 1967). A more detailed description of population survey methods is contained in earlier publications (Hartman et al. 1982; Narver and

Andersen 1974). Estimates of the total stream population were extrapolated from estimates in the study sections which encompassed at least 10% of the total stream length.

Coho fry and smolts moving downstream and adults returning upstream were enumerated, measured, and weighed at a counting fence. During 1971, a structure was 100 m upstream of the permanent fence, built in March 1972 (see Fig. 1, Scrivener and Andersen, these proceedings). The permanent fence consists of flow divider screens and five fan traps capable of screening 6 m^3/s of water. At higher flows, known portions were subsampled. Fence construction and operations are explained more fully elsewhere (Hartman et al. 1982; Lill and Sookachoff 1974; Narver and Andersen 1974).

The analysis of coho population dynamics that follows is presented in sections: (1) egg deposition and egg loss; (2) postemergence loss; (3) summer loss; (4) winter loss; (5) postemergence growth; (6) summer growth; (7) end-of-summer biomass and population size; (8) smolt production; and (9) adult returns. The partitioning of time between winter- and summer-life stanzas is arbitrary but largely determined by the timing of population estimates and fence operations.

Multiple regression analyses were used to relate instantaneous loss and growth rates to sets of environmental descriptors. Given the small sample size ($n = 10$-12), multiple regressions must be interpreted with caution. With so few data points, regressions tend to be heavily influenced by outliers. Residual analyses were used throughout to ensure that variables entering regressions were not doing so because of the undue influence of outliers.

RESULTS AND DISCUSSION

Egg Deposition and Egg Loss

The number of eggs deposited is estimated from the number and length of females entering the creek to spawn and a relationship between fecundity and length (Symons 1979).

The total number of fry produced is the sum of the fry estimated to be in the creek at the first population estimate in late May-early June plus the cumulative number of fry that had passed downstream through the fence prior to this estimate (Narver and Andersen 1974; Andersen and Narver 1975; Andersen 1978, 1981). In estimating the number of fry produced in this manner, undetected fry loss in the stream prior to the first population estimate is assumed to be small, an assumption that cannot be assessed.

The proportion of eggs lost is calculated as:

$$1 - \frac{\text{total no. fry produced}}{\text{estimated no. eggs deposited}}$$

The egg mortality rate is defined as:

$$\frac{\ln\,(\text{total no. fry produced/est. no. eggs deposited})}{\text{Julian day of 50\% fry downstream} + 61}$$

Expressing egg mortality as a rate is problematic. The duration of the period over which egg mortality could occur can only be estimated, since exact spawning and emergence times are unknown. Spawning has been arbitrarily set as November 1. On this date, 60% to 90% of returning adults had passed upstream, through the fence. First emergence is assumed to coincide with appearance at the fence of fry moving downstream. This assumption is supported by the observation that fry are first seen at the fence at roughly the same time that they are seen in the stream by divers (Tschaplinski and Hartman, in press).

Estimated egg deposition has ranged from a low of 89 900 in 1976 to 308 000 in 1979 (Fig. 1a). Prior to logging (1971 to 1976), there was little variation in potential egg deposition. The considerable variability in following years was largely due to changing numbers of female spawners (see section on adult returns).

The proportion of eggs lost has varied from a low of 0.460 in 1971 to a high of 0.883 in 1980 (Table 1; Fig. 1b). The largest egg losses have occurred in the last 3 years (Fig. 1c). Prior to 1978, the observed survivals of 26% are similar to those observed in other undisturbed coastal streams (McNeil 1969; Phillips 1971). In the 3 winters 1978-1979, 1979-1980, 1980-1981, survival has become progressively lower (Table 1), reaching the lowest value so far observed in the study of 11.7%. Trends in egg loss rates are similar to those in the proportions of eggs lost (Fig. 1b). Increased loss rates since 1978 are particularly marked.

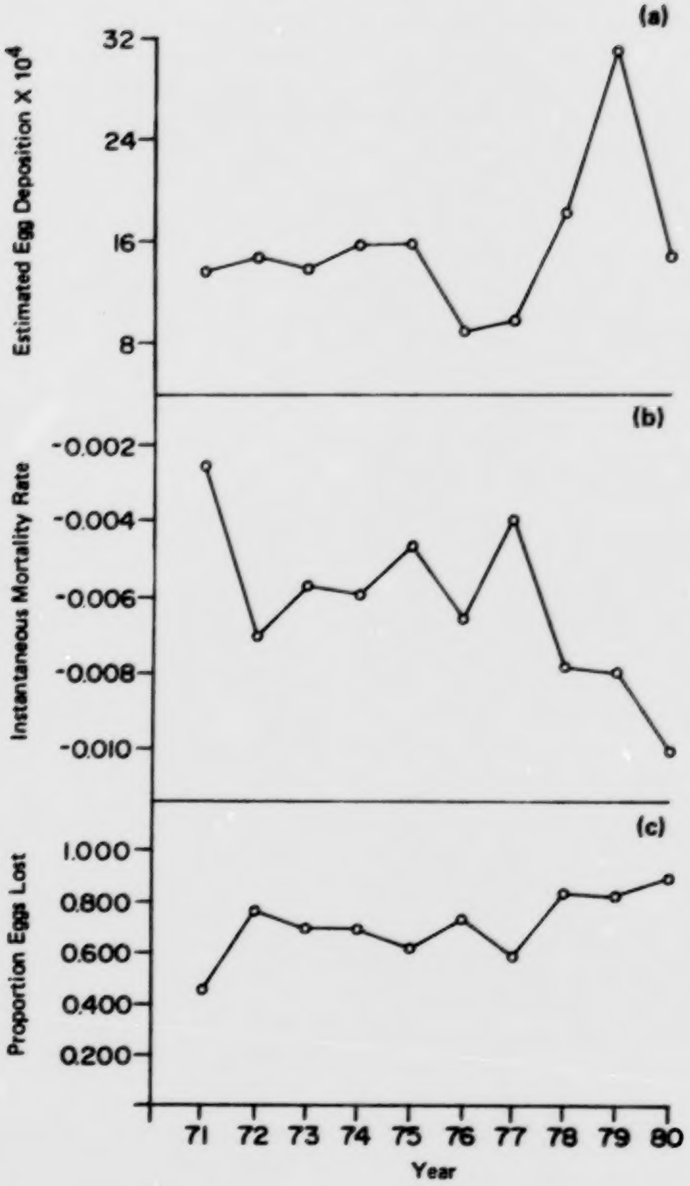

Fig. 1. Estimated egg deposition, instantaneous daily mortality rates of eggs, and the proportion of eggs deposited that did not produce viable fry for coho in Carnation Creek. The year given is that of egg deposition. Intensive logging began in the winter of 1976-1977.

Table 1. Coho egg deposition and egg loss data.

Year	Estimated Egg Deposition	No. of Emergent Fry	Proportion of Eggs That Failed to Produce Fry	Instantaneous Daily Egg Loss Rate	No. of Days From Nov. 1 to 50% Emergence
1971	131 220	70 908	0.4596	–0.002642	206
1972	148 500	35 121	0.7635	–0.007282	188
1973	137 380	40 846	0.7027	–0.005860	194
1974	157 500	46 789	0.7029	–0.006009	178
1975	158 800	60 972	0.6160	–0.004786	198
1976	89 900	23 365	0.7401	–0.006771	161
1977	96 390	39 474	0.5905	–0.004095	166
1978	180 300	31 515	0.8252	–0.007928	174
1979	308 000	55 413	0.8201	–0.008053	169
1980	146 250	17 093	0.8831	–0.010630	145

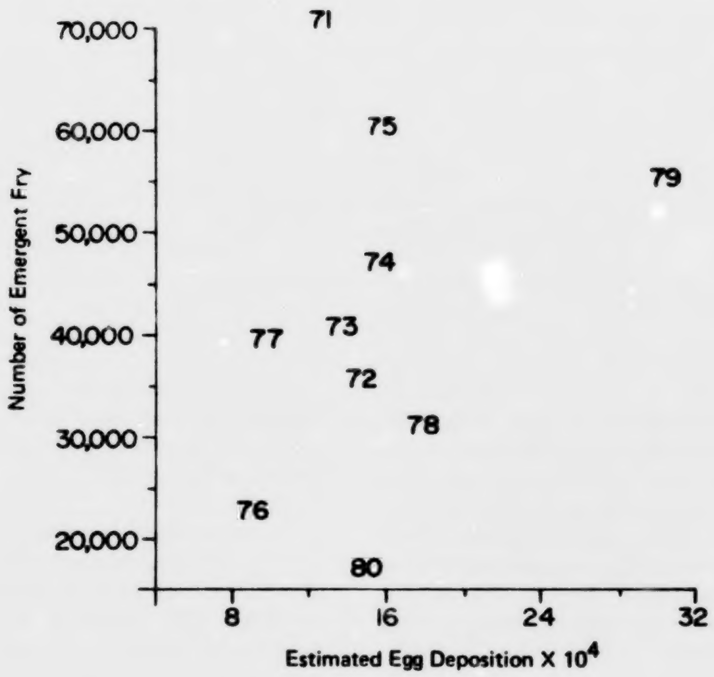

Fig. 2. Numbers of emergent fry as a function of estimated egg deposition. The years shown on the plot are those of egg deposition.

Table 2. Variables used to describe winter flow, temperature, and sediment conditions in Carnation Creek. Unless noted otherwise, the period summarized was December 1 through March 31 inclusive.

Flow:

1. Flow levels: HR64, HR128, HR256, HR512, HR1026.

   The total number of hours during which flow exceeded 1.812, 3.624, 7.247, 14.495, and 28.989 m^3/s.

2. Flow level changes: PLUS64, PLUS128, PLUS256.

   The total number of times that flow increased over a 48-hour period by 1.812, 3.624, or 7.247 m^3/s.

3. Speed at which flow changed: VEL16, VEL32, VEL64, VEL124.

   The total number of times that the rate of change of flow exceeded 0.453, 0.906, 1.812, or 3.624 m^3/h.

Temperature:

1. Mean November temperatures: TEMPNV1, TEMPNV30.

   Mean daily stream temperatures at B-weir on November 1 and 30.

2. Minimum and maximum winter temperatures: TMIN, TMAX.

   Minimum and maximum temperatures at B-weir.

Sediment:

1. Percent fine composition: SEDSM, SEDLG.

   Percentage (by weight) of fines less than 0.297 mm and 2.38 mm. Values were averaged for the streambed above B-weir.

The number of fry produced shows no relationship to potential egg deposition (Fig. 2). The absence of density-dependent mortality of eggs is not unexpected. The area suitable for spawning is probably greater than 1000 m^2, although no reliable estimate is available. With such a large available area and so few spawners, redd superposition is unlikely and, consequently, density-dependent effects are not expected (McNeil 1969).

Multiple regression analyses were used to identify the best predictive variable set for the egg loss rate and the proportion of eggs lost (Table 3). The independent variable set used in the regression analyses included 12 measures of flow conditions, two temperature measurements, and two measures of gravel composition (Table 2).

Both the mortality rate and proportion of eggs lost are best predicted by the maximum mean daily temperature and by the percent sediment that passes through a 2.38 mm sieve (Table 3). Measures of flow conditions do not enter the regressions and are only weakly related to egg loss.

Maximum winter temperatures have generally increased since logging began, and these increases have been due, in part, to logging and to climatic

Table 3. Regression of instantaneous egg loss rate and proportion of eggs lost on winter flow, temperature, and sediment variable set. Notation for independent variables, as per Table 2.

Dependent Variable	Independent Variable	Parameter Estimate[a]	Cumulative R^2
Instantaneous egg loss rate	(intercept)	0.023558	--------
	TMAX	–0.00973	0.384
	SEDLG	–0.002046	0.661
Proportion of eggs lost	(intercept)	–0.83504	--------
	TMAX	0.04778	0.271
	SEDLG	0.10699	0.485

[a] All significant at least at 5% level.

variability (Holtby and Newcombe, these proceedings). It is improbable that the generally warmer winter temperatures have adversely affected egg survival directly. Increasing temperatures could be gauging logging-related deterioration in the stability and quality of the stream channel that is reducing egg survival (Toews and Moore 1982, these proceedings). Changes in channel morphology, such as bank erosion, channelization, and large-scale deposition of gravel can be readily seen in the creek and such degradation appears to be occurring at an accelerated pace However, it is very difficult to quantify the changing channel morphology in a way that is compatible with statistical analyses and interpretable in terms of potential effects on eggs.

Higher winter temperatures have led to earlier emergence since logging began (Hartman et al. 1982). Earlier emergence increases the probability that fry will be exposed to high flow conditions during which they could be washed from the creek (see following section on postemergence loss). During high water, it might also be possible for fry to disperse from the creek onto the floodplain and some could be stranded on the floodplain by receding flows. This mortality would appear as egg loss because of the way in which egg loss and postemergence loss were calculated (see following section).

The negative effects of increased fine sediment deposition stem from decreased gravel permeability and armoring effects preventing successful emergence. There is abundant literature demonstrating the adverse effects of these processes on incubating salmon eggs (reviewed by Phillips 1971).

Decreased 0_2 permeability usually results from deposition of clay and silt particles which clog the interstitial spaces of the gravel. Clay and silt particles are typical products of road construction and road runoff. There has been little increase in these materials since logging began (Scrivener and Brownlee, these proceedings), and gravel quality relative to other systems has not been reduced to the point where increased mortality is expected (Koski 1966). Armoring effects are produced by sand deposition. There has been a marked increase in the amount of sand in the gravel since logging began. This material is thought to originate from bank erosion along the creek. Since the rate of bank erosion appears to be increasing, gravel quality is expected to continue to decline and further reduce the production of coho fry.

Postemergence Mortality

The postemergence period is considered to be the period between emergence of the fry from the gravel and the first population estimate usually made in late May and early June. Since emergence was not studied directly, emergence time was arbitrarily set as the day the total number of fry that passed through the fence reached 5% of the ultimate total.

The mortality and loss that is estimated from the difference of estimated egg deposition and the first in-stream population estimate has been arbitrarily divided into "egg mortality" and "postemergence loss". In doing so, we are assuming that the fry passing downstream through the fence are the sole loss imposed on the fry that successfully emerged. If additional in-stream losses have occurred, then our estimates of egg mortality are too high, and corresponding estimates of postemergence loss are too low.

The numbers of fry lost in the postemergence period range from 5 078 (1979) to 104 133 (1971) (Table 4). Total numbers emerged vary from 17 093 (1981) to 141 163 (1971). There is no identifiable temporal trends in the numbers lost (Fig. 3a). However, loss rates were generally higher in the prelogging period (Fig. 3b). This is largely a consequence of the lengthening of the postemergence period after 1976 that was due to progressively earlier fry emergence (Hartman et al. 1982).

The magnitude of fry loss and loss rates are dependent on flow conditions around the time of emergence. Many fry appear to move seaward on rising hydrographs of the first few storms after emergence, but the numbers of fry moving are not related to the intensity of flow (Hartman et al. 1982). For these reasons, it is difficult to show strong statistical relationships between general descriptors of flow conditions and fry loss. To do so would require analysis of specific storm events and day-to-day monitoring of the location, numbers, and behavior of emerging fry. When streamflow events are summarized for the period March to May 31 of each year, fry loss rates are weakly related to the total flow, to the number of hours that flow exceeded 1.81 m^3/s (Table 4, Fig. 4), to the number of rapid flow increases, and to the mean stream temperature. The fry loss rate in 1975 was the largest yet observed, and this year is a clear outlier from all loss-flow relationships.

The impacts of flow regimes on emergent fry loss have been confounded by the earlier emergence that has occurred since logging began (Table 4). Earlier emergence exposes fry to higher probabilities of encountering high flows, which probably increases the probability that the fry will be physically displaced or lost from the creek (Hartman et al. 1982; Scivener and Andersen, these proceedings).

Continuing deterioration in the quality of the physical habitat has not yet had any detectable impact on the survival of emerged fry. It is probable, however, that fry are unable to maintain their positions in certain parts of the stream where channelization has been severe, but it is unknown whether this leads to their loss from the system or simply to some downstream displacement. Clearly, additional study of this aspect of the early in-stream ecology of coho is warranted.

In addition to those fry that are behaviorally displaced from the creek, it is probable that variable numbers of fry are physically displaced during high flow events. It is probably not correct to assume that fry lost in the spring are all "surplus" to the system (Mason and Chapman 1965). Considerable losses occurred in 1981, despite low emergence. Partly as a consequence of this substantial fry loss, the system was "underseeded" during the summer of 1981.

Summer Loss

Instantaneous loss rates were estimated from the late May-early June and September population estimates (Narver and Andersen 1974; Andersen and Narver 1975; Andersen 1978, 1981). Some loss can be accounted for by fry and 1+ fish that left the creek and were enumerated as they passed downstream through the fish-counting fence.

An instantaneous loss rate was calculated as:

$$\ln \frac{\text{population at last estimate (Sept.)}}{\text{population at first estimate (June)}} \;/\,\Delta\,\text{time (days)}$$

The numbers of 0+ and 1+ coho in the creek on September 15 were then interpolated from the mortality rate and the June population estimate.

Prior to logging, the numbers of 0+ coho in the creek on September 15 varied between 8 897 (1973) and 13 280 (1976) (Table 5). In 1980, densities of 0+ fish increased to 1.89 the prelogging average, while in 1981, observed densities were only 0.487X the prelogging average. Trends for the 1+ fish were similar, although variability was somewhat higher (Table 5).

Total mortality during the summer was highly variable, ranging from 1 192 in 1981 to 34 335 in 1976

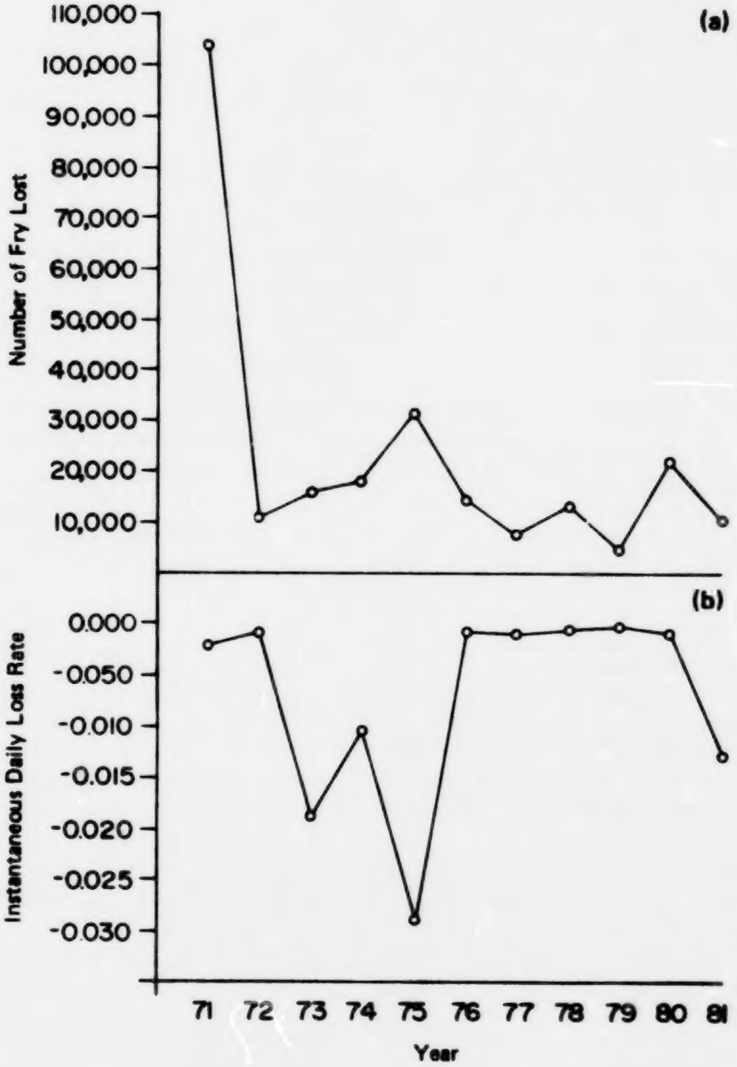

Fig. 3. (a) Numbers of coho fry first from Carnation Creek between emergence and the first population estimate in late May-early June.

(b) Instantaneous daily loss rate of coho fry over the same period.

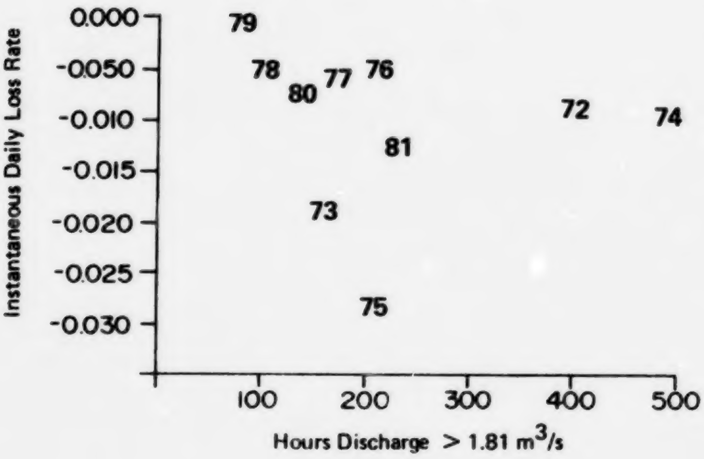

Fig. 4. Instantaneous daily loss rates of coho fry during the postemergence period as a function of the number of hours that flow exceeded 1.81 m^3/s.

Table 4. Coho postemergence population data.

Year	Julian Date of Emergence 5%	Julian Date of Emergence 50%	No. of Fry Lost	Instantaneous Daily Loss Rate	Hours Discharge > 1.81 m^3/s (March 1 to May 31)
1971	101	124	104 133	–0.0203	--------
1972	115	145	10 817	–0.0096	397.0
1973	106	127	15 585	–0.0189	158.0
1974	91	133	18 043	–0.0106	495.5
1975	105	117	30 194	–0.0288	208.5
1976	99	137	14 310	–0.0067	219.5
1977	85	100	7 802	–0.0077	187.5
1978	87	105	13 326	–0.0059	111.5
1979	97	113	5 078	–0.0028	98.5
1980	88	108	21 785	–0.0078	128.5
1981	66	84	10 446	–0.0126	236.0

Table 5. Coho summer mortality data for 0+ (fry) and 1+ (yearling) fish.

Year	Geometric Mean Population Number (GMPN)		Total No. of Fish Lost During Summer		Instantaneous Daily Loss Rate	
	0+	1+	0+	1+	0+	1+
1971	20 934	993	25 194	1 163	–0.0125	0.0057
1972	22 269	1 157	24 305	2 887	–0.0212	–0.0119
1973	13 312	1 372	10 464	1 985	–0.0065	–0.0028
1974	16 856	1 140	10 342	1 739	–0.0053	–0.0004
1975	13 808	834	5 132	313	–0.0031	0.0079
1976	23 983	1 160	34 332	1 543	–0.0106	0.0010
1977	12 846	1 028	4 960	1 299	–0.0029	0.0028
1978	16 903	1 222	15 219	1 966	–0.0077	–0.0020
1979	18 702	1 592	13 207	1 775	–0.0067	–0.0006
1980	26 544	2 070	12 677	1 541	–0.0044	–0.0006
1981	6 022	1 135	1 192	2 878	–0.0017	–0.0086

for 0+ fish (Table 5). Approximately two-thirds of the total mortality is accounted for by fish moving through the counting fence (Table 5). Losses for the 1+ fish cannot be accurately estimated. In 5 of the 11 years, population estimates in September were higher than those in June or July (shown as positive mortality rates, Table 5.) The September estimates are usually conducted at times of lower flows when the pool-dwelling coho are more susceptible to shockers and seines. Most 1+ fish are caught with the shocker, not with the seine. During the pre-logging phase of the study, conductivities were lower in May-June than in September and, consequently, the sampling efficiency on 1+ fish increased over the summer. The distribution of 1+ fish is thought to be very patchy immediately following the winter, which would further reduce the reliability of the May-June estimate. In addition, habitat contraction over the summer possibly reduces accessibility to side channels and tributaries, forcing more fish into the main creek where they are censused. Although fish are known to inhabit small side channels and tributaries, these areas are very difficult to sample quantitatively and little effort has been made to do so. Since 0+ fish do not make extensive use of side channels until late fall. Sampling problems in side channels and tributaries should not affect population estimates of the 0+ fish. Further analysis of coho population data assumes that the comparison of the *relative* values of mortality rates and population estimates for the 1+ fish is valid. The independent variable set used in the following regression analyses is listed in Table 6.

Summer loss rates of 0+ coho is density-dependent (Fig. 5a). Density dependence could be expected solely from a consideration of the relative consistency of fall populations (maximum = 153 X minimum; excluding 1980, 1981) compared to spring populations (maximum ~ 3.0 X minimum; excluding 1980, 1981).

For 0+ fish, 94.6% of the variance in summer mortality rates can be accounted for by a multiple regression model incorporating four variables (Table 7). Density dependence accounts for 23.6% of the total variation in loss rates of 0+ fish. Additional variation was accounted for by a high flow variable (MNFLOW4, the number of 5-day periods in which minimum flow exceeded 100 cfs), by the proportion of the streambank that was vegetated (PVEG), and by the maximum stream temperature observed on the day of minimum flow (FLOWTEMP).

Table 6. Variables used in multiple regression analysis of summer loss and growth rates. Data were summarized for the period May 1 through September 30 inclusive.

Flow:

1. Total flow (m^3): TOTFLOW.
2. Proportion of time flow was less than 0.02831, 0.05662, or 0.1132 m^3/s: PTIME1, PTIME2, PTIME3.
3. Number of 5-day periods when mean daily flow was < 0.142, < 0.2831, > 1.4155, or > 2.831 m^3/s: MNFLOW1, MNFLOW2, MNFLOW3, MNFLOW4.
4. Minimum summer flow observed at B-weir (m^3/s): MINFLOW.

Temperature:

1. Centigrade thermal summation (degree days): CTU.
2. Maximum temperature (C): TMAX.
3. Maximum temperature observed on day of minimum flow (C): FLOWTEMP.

Indices of Logging:

1. Proportion of streambank vegetated in anadromous fish zone: PVEG.
2. Proportion of streambank logged in anadromous fish zone (revegetation not considered): PCUT.

Table 7. Regression for summer loss rate of 0+ coho. Notation of independent variables, as per Tables 5 and 6.

Dependent Variable	Independent Variable	Parameter Estimate[a]	Cumulative R^2
Instantaneous daily loss rate	(intercept)	0.1359	-------
	Log_{10} geometric mean density	–0.0234	.236
	MNFLOW4	–0.0069	.397
	PVEG	–0.0224	.795
	FLOWTEMP	–0.0018	.946

[a] All significant at least at 5% level.

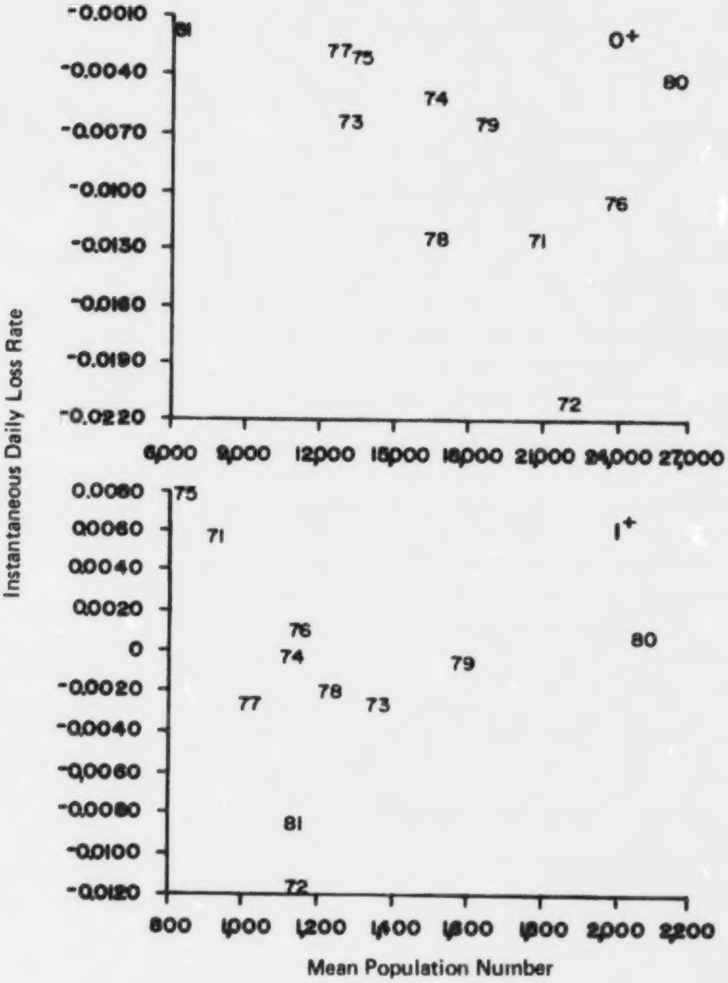

Fig. 5. Instantaneous daily loss rates during the summer for coho fry (0+, top) and yearlings (1+, bottom) as functions of geometric mean population numbers.

MNFLOW4 entered the regression largely to correct for the very high loss rate observed in 1972. Summer storms of such intensity occurred in only 3 years (1972, 1979, and 1981). Examination of the residuals after correcting for density indicated that loss rates were relatively high in all three of these years, even though the loss rates obtained for 1979 and 1981 were among the lowest observed. High flows occurring in summer storms are probably a direct source of mortality; fish that are unable to locate refugia are washed from the system.

After correcting for density and high-flow events, loss rates decreased as the streambank vegetation was reduced. Streambank clearing has led to higher stream productivity because of increased light levels (Stockner and Shortreed 1976) and/or temperatures (Holtby and Newcombe, these proceedings). Increased stream productivity has probably increased the rate of food supply to the juvenile coho, possibly contributing to reduced loss rates.

A further 15.1% of the total variance was accounted for by the maximum temperature on the day of minimum flow. It is possible that high temperatures themselves contributed directly to increased loss. However, the maximum temperature observed thus far in the study (19.3°C, 1981) does not seem sufficient to have caused mortality. Another possibility is that the increased maximum temperatures, observed since logging, have been paralleled by gradual degradation of habitat quality, which has resulted in higher summer losses.

For 1+ fish, 56.1% of the variability in the loss rates can be explained by a model incorporating 2 variables (Table 8a). Loss rates were highest in two of the three years in which there were intense summer storms (Table 5). A similar correlation was observed for the 0+ fish. Loss rates also increased as the probability of low-flow events increased. This probability was measured as the number of 5-day periods (May to October) in which minimum flow was less than 0.02831 m^3/s. The mechanism by which yearling coho are adversely affected by low flows is unclear. It is unlikely that significant competition occurs among 1+ fish for either food or space. This conclusion is supported by two observations. First, mortality is not dependent on density, either of 1+ fish alone or total coho biomass (Table 8b). Density dependence is indicative of competitive interactions. Second, loss rates are not correlated with measures of minimum available habitat space (Table 8b). This relationship is expected if the number of 1+ fish in the stream is being limited by the available habitat space.

Winter Mortality

First-winter mortality was estimated from the September and the following June population estimates. Smolts which passed the fence prior to the June population estimates were not considered to be mortality and were added to the June population estimate for these calculations. In addition to errors in the population estimates, both mortality estimates are subject to unknown errors caused by smoltation prior to the beginning of fence operation in early March. However, peak smolt movements have occurred during late April and May and smolt movements prior to the inception of fence operations are thought to be insignificant. Further errors are caused by inefficient fence operation at flows exceeding 6 m^3/s. The majority of smolts pass the fence in advance of peak flows, and consequently this error is also thought to be insignificant.

Table 8a. Regression for summer loss rate of 1+ coho. Notation of independent variables, as per Table 6.

Dependent Variable	Independent Variable	Parameter Estimate[a]	Cumulative R^2
Instantaneous daily loss rate	(intercept)	0.00273	....
	MNFLOW4	−0.00880	0.441
	PTIME1	−0.02429	0.561

Table 8b. Product moment correlations between loss rates for 0+ and 1+ coho and (1) coho abundance and (2) estimates of minimum available habitat space.

Variable	Correlation With Summer Loss Rate 0+	Correlation With Summer Loss Rate 1+
1. Geometric mean population size:		
– 0+	–0.657*	0.233
– 1+	0.175	–0.274
– Total	–0.648*	0.209
2. Available habitat area:		
– Pool area	0.116	0.350
– PCUT: proportion of streambank logged	0.511	–0.273

* $p < 0.05$.

Instantaneous mortality rates were calculated using the formulae:

For 1+ fish:

Instantaneous monthly mortality rate =

$$30 \times \ln \frac{\dfrac{\text{June pop. est. + no. 1+ smolts}}{\text{previous Sept. pop. est.}}}{{}^{t}\text{June est.} - {}^{t}\text{Sept. est.}}$$

For 2+ fish:

Instantaneous monthly mortality rate =

$$30 \times \ln \frac{\dfrac{\text{2+ smolts}}{\text{previous Sept. pop. est.}}}{{}^{t}\text{June est.} - {}^{t}\text{Sept. est.}}$$

Numbers of fish and their lengths on November 1 (Table 9) were estimated from summer loss and growth rates and population estimates made in late September.

First-winter mortality rates have been variable but, in general, have been lower in the years since logging began (Table 9; Fig. 6a). Second-winter loss rates were less variable but show a gradual increase over the course of the study (Table 9, Fig. 6b). However, due to problems in the abundance estimates of 1+ fish, these mortality estimates should be treated with caution.

Fish length at the beginning of the winter (November 1) is correlated with overwinter survival ($r = 0.755$, 22 df; $p < 0.001$; Fig. 7). For coho entering their first winter, survival improves with increasing size. Preliminary mortality estimates for 1981-1982 indicate that the 0+ fish entering that winter were the largest yet observed (72.4 mm) and had the lowest observed mortality rate (Table 9).

Observed mortality rate has increased with increasing size for the 1+ fish, up until 1981-1982 when preliminary figures indicate that the largest 1+ fish yet observed experienced low mortality (Table 9). If only during-logging years are considered, then mortality rate decreases with increasing size and the 1981-1982 observed value rate is consistent with the fish's large size. High survivorship in the 1981-1982 winter was unexpected due to the severity of flow conditions.

Winter mortality rates are density-dependent for 1+ fish, but not for the 0+ fish (Fig. 7b). However, mortality appears density-dependent only because of the mortalities observed at the extremes of density. At intermediate densities, where 7 of 11 years fall, there is no density dependence. Although there are several possible explanations, including measurement error,

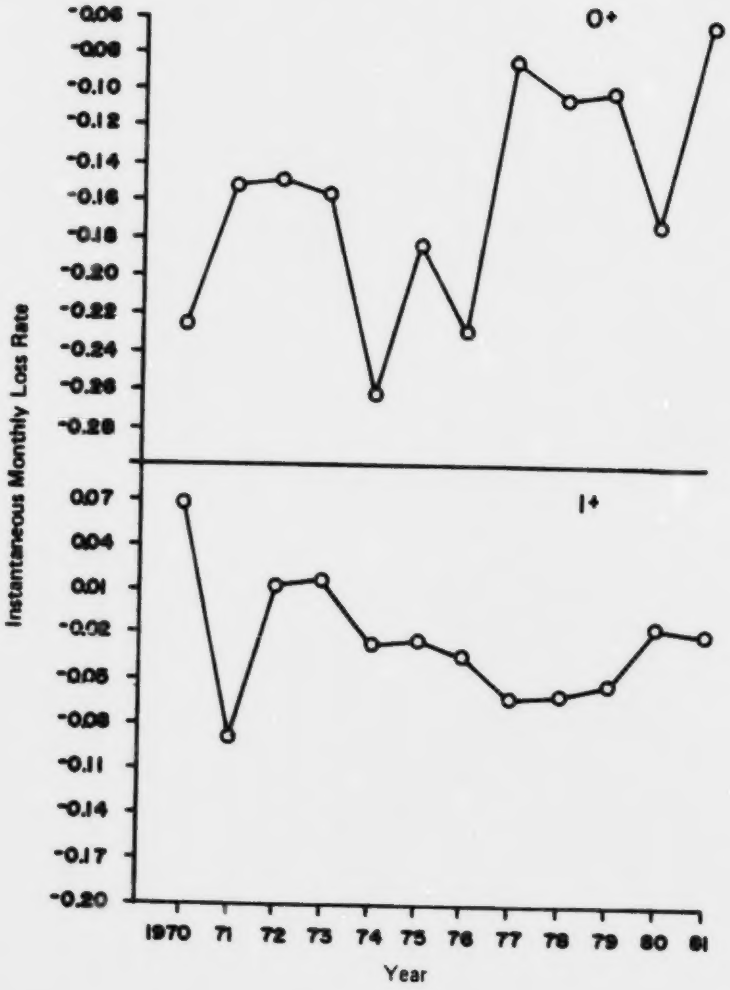

Fig. 6. Instantaneous monthly loss rates for 0+ and 1+ coho for the winter period November 1 through late May-early June.

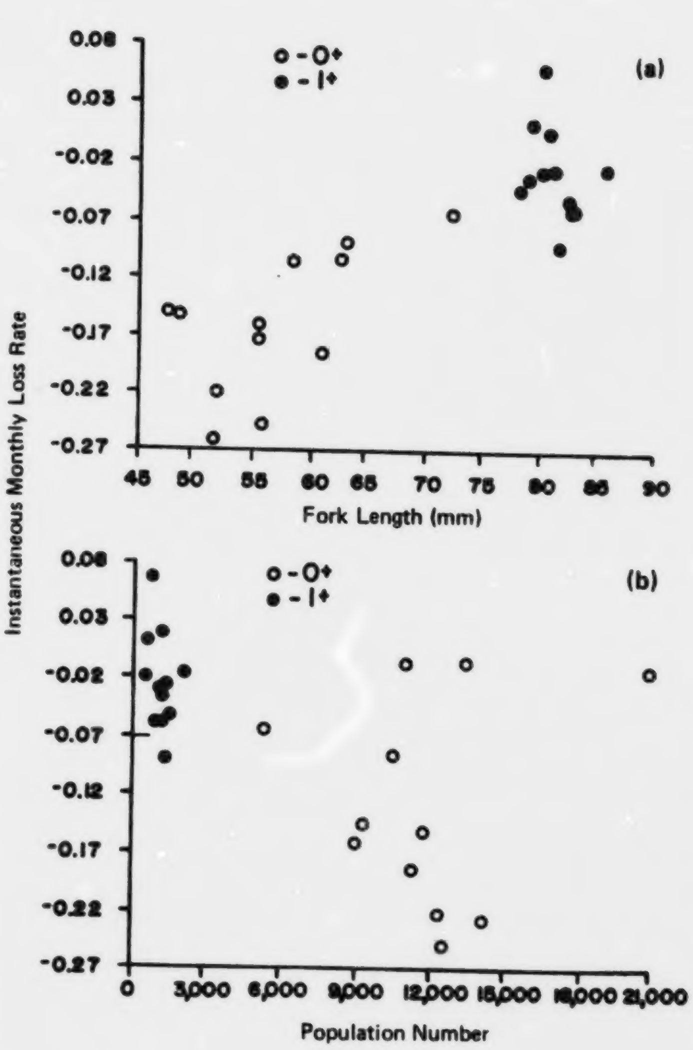

Fig. 7. Instantaneous monthly loss rates during the winter for coho fry (0+) and yearlings (1+) as functions of: (a) fork length and (b) population number on November 1.

Table 9. Coho winter loss data.

Year	Population Number (November 1)		Fork Length (November 1)		Instantaneous Monthly Loss Rate	
	0+	1+	0+	1+	0+	1+
1970	14 137	790	55.7	80.2	–0.2252	0.0675
1971	11834	1 286	48.9	81.7	–0.1537	–0.0883
1972	9 252	702	47.6	80.7	–0.1505	0.0107
1973	9 071	1 229	55.5	79.4	–0.1597	0.0169
1974	12 460	1 112	52.2	80.6	–0.2628	–0.0288
1975	11 482	1 333	60.9	78.9	–0.1832	–0.0270
1976	12 327	1 232	52.6	78.5	–0.2199	–0.0346
1977	10 603	1 238	63.6	82.8	–0.0848	–0.0598
1978	10 927	1 089	58.7	82.9	–0.1055	–0.0582
1979	13 230	1 547	63.2	83.3	–0.1026	–0.0510
1980	20 952	2 142	55.6	80.9	–0.1724	–0.1959
1981	5 455	685	72.4	85.7	–0.0630	–0.0200

the observed pattern suggests that high-quality overwintering habitat is limited for the larger 1+ fish. Apparently, however, enough high-quality overwintering habitat remained in the creek through 1981 to allow high overwinter survival.

Winter mortalities are not related to winter flow conditions, as indicated by lack of significant correlations between mortality rates and various measures of flow duration, volume, and rate of change. Mortality rates are similarly unrelated to winter temperature regimes or changes in spawning gravel sediment composition (a measure of gravel disturbance and sedimentation). There is suggestive evidence that the loss of large-debris streambank erosion and channelization has adversely affected overwinter survival (Tschaplinski and Hartman, in press), at least in some parts of the creek.

Absence of correlations between overwinter mortality and physical stream conditions or environmental parameters could be due to several factors. The overwintering habitat in the main creek that has been seriously degraded amounts to only 25% (approximately) of available main creek habitat (from 1400 m to 2200 m). Side channels, which on a wetted-area basis are more important to overwintering fish than to the main creek (Bustard and Narver 1975; Tschaplinski and Hartman, in press), have not been affected. Consequently, it is possible that habitat degradation has not been extensive enough to have caused a detectable decline in overwinter survivorship for the system as a whole. After logging began, fish entering the winter have become progressively larger (Table 9). Increased size, which has in turn increased survival potential, has possibly compensated for decreased habitat quality.

The effects of intensive logging along larger stream lengths are unknown but would be expected to be severe. The long-term effects of debris loss and channelization to the extent that has already occurred are also unknown, but the effects are potentially very damaging. It has been suggested that stream productivity might return to prelogging levels within 15 years (Murphy et al. 1981). The size at which fish enter the winter season should decline with decreasing stream productivity. Continued habitat degradation coupled with decreased fish size could significantly reduce coho production in Carnation Creek.

Postemergence Growth

Fry of the year have been significantly larger on June 1 since logging began (Table 10). The importance of earlier emergence and higher growth rates to the larger observed sizes on June 1 were assessed by estimating sizes that fry in the postlogging years would have obtained given prelogging conditions (Table 10).

Assuming only that emergence occurred at the same time (on average) as observed during the prelogging years (Table 10 "A"), estimated sizes on June 1 in the during-logging years are less than the observed sizes (Fig. 8 "A"). Assuming only that growth rates in the during-logging years were the same as during the prelogging years (after correction for density, Table 10 "B"), estimated sizes are again less than those observed (Fig. 8 "B"). Assuming both the above conditions (Table 10 "C"), estimated sizes on June 1 for the during-logging years are approximately equal to those observed in the prelogging years. It can be concluded that both factors—earlier emergence and increased growth rates during logging—contributed to the larger sizes observed after logging began.

In a similar analysis, Hartman et al. (in press) have shown that the larger size obtained by underyearling coho on June 1 results in larger fish entering their first winter. Larger size results in lower overwinter mortality. Surprisingly, growth achieved between emergence and June 1 has important ramifications to survival the following winter. Significantly, logging activity, by increasing winter temperatures and speeding up emergence which in turn lengthens the period for early summer growth, affects population dynamics a year later.

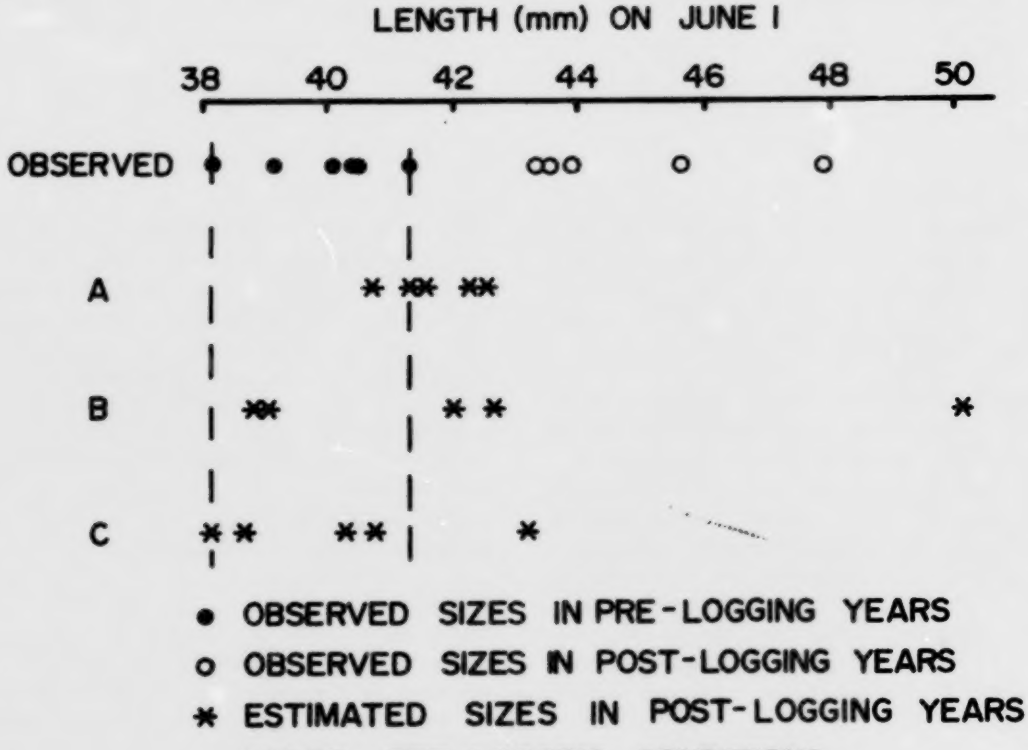

Fig. 8. Observed and predicted sizes of coho fry during prelogging and postlogging years. The three assumptions (A, B, and C) used in predicting fry size are explained in the heading of Table 10.

Table 10. Estimated sizes on June 1 for the during-logging years were calculated under three sets of assumptions:

(A) Using the growth rates observed during the logging years and assuming an emergence date equal to the observed prelogging average (Julian date = 119.7).

(B) Using the observed emergence date and a prelogging growth rate corrected for observed density; growth rate = $0.02616 - 0.00551 \times \log_{10}$ (density).

(C) Assuming both the average prelogging emergence date and the estimated growth rate.

	Prelogging Years				During-Logging Years			Estimated Size (mm) Under Condition		
Year	Growth Rate[a]	Density[b] (Total Pop.)	Size on June 1 (mm)	Year	Growth Rate	Density (Total Pop.)	Size on June 1 (mm)	A	B	C
1972	0.00016	38 587	38.2	1977	0.00289	19 069	43.5	40.8	42.8	40.4
1973	0.00148	27 300	40.4	1978	0.00193	32 127	43.5	41.6	42.0	40.8
1974	0.00159	25 194	40.4	1979	0.00405	28 865	43.9	41.4	39.1	38.2
1975	0.00268	27 874	41.3	1980	0.00355	43 168	45.7	42.6	39.3	38.8
1976	0.00044	53 261	40.1	1981	0.00331	10 612	47.9	42.3	50.2	43.2

[a] Instantaneous daily growth rate.

[b] Densities are geometric means of emergence estimates and first population estimates and are total creek populations.

Summer Growth

The summer has been arbitrarily defined as the period between the first population estimate (late May-early June) to the third population estimate (September). Instantaneous growth rates for total length and weight were calculated using the formula:

$$\text{Growth rate} = \ln\left\{\frac{\text{length}_3\ (\text{or weight}_3)}{\text{length}_1\ (\text{or weight}_1)}\right\} / t_3 - t_1$$

where the subscript indicates the population estimate and "t" is the Julian date of the estimate.

Growth rates of 0+ fish have been, on average, higher since logging began, with the exception of 1980 when the growth rate was the lowest yet observed (Table 11). Growth rates of 1+ fish have declined over the course of the study (Table 11). Growth rates of 0+ fish are strongly density-dependent (Fig. 9a). The low (high) growth rates of 0+ in 1980 (1981) can be accounted for by the large (small) population sizes in the summers of those years. Growth rates of 1+ fish are not density-dependent (Fig. 9b). The lack of density dependence is due to the high growth rate observed in 1972 and 1973 at average population levels.

A multiple regression model incorporating three variables explains 83.7% of the variance in the growth rates of 0+ fish (Table 12); 68.4% is accounted for by density dependence. A further 1.3% of the variance was accounted for by the number of periods when mean daily flow was less than 0.283 m^3/s. The small amount of additional explained variance added by this variable suggests that it has little underlying biological importance, but instead is correcting for an outlier (1981) after the fitting of density. The third variable, the proportion of time that flows were less than 0.0283 m^3/s, accounts for a further 14% of the variance. All else constant, growth rates are lower in years of prolonged low flows. This probably results from a combination of the effects of higher effective densities and lower food delivery rates. The magnitude of the minimum flow and estimates of habitat area available on the day of lowest flow were not significantly correlated with summer growth rates, suggesting that the duration and frequency of occurrence of low-flow events are of greater significance than transitory low-flow events.

Table 11. Coho summer growth data for fry (0+) and yearlings (1+).

Year	Geometric Mean Population Number		Instantaneous Daily Growth Rate (Fork Length)		Instantaneous Daily Growth Rate (Weight)	
	0+	1+	0+	1+	0+	1+
1971	20 934	993	0.00194	0.00178	0.0077	0.0047
1972	22 269	1 157	0.00184	0.00317	0.0065	0.0092
1973	13 312	1 372	0.00219	0.00304	0.0091	0.0101
1974	16 856	1 140	0.00185	0.00170	0.0079	0.0045
1975	13 808	834	0.00253	0.00264	0.0089	0.0067
1976	23 983	1 160	0.00185	0.00141	0.0074	0.0045
1977	12 846	1 028	0.00271	0.00114	0.0089	0.0035
1978	16 903	1 222	0.00231	0.00117	0.0072	0.0029
1979	18 702	1 592	0.00253	0.00086	0.0077	0.0021
1980	26 544	2 070	0.00114	0.00083	0.0044	0.0020
1981	6 022	1 135	0.00309	0.00149	0.0098	0.0037

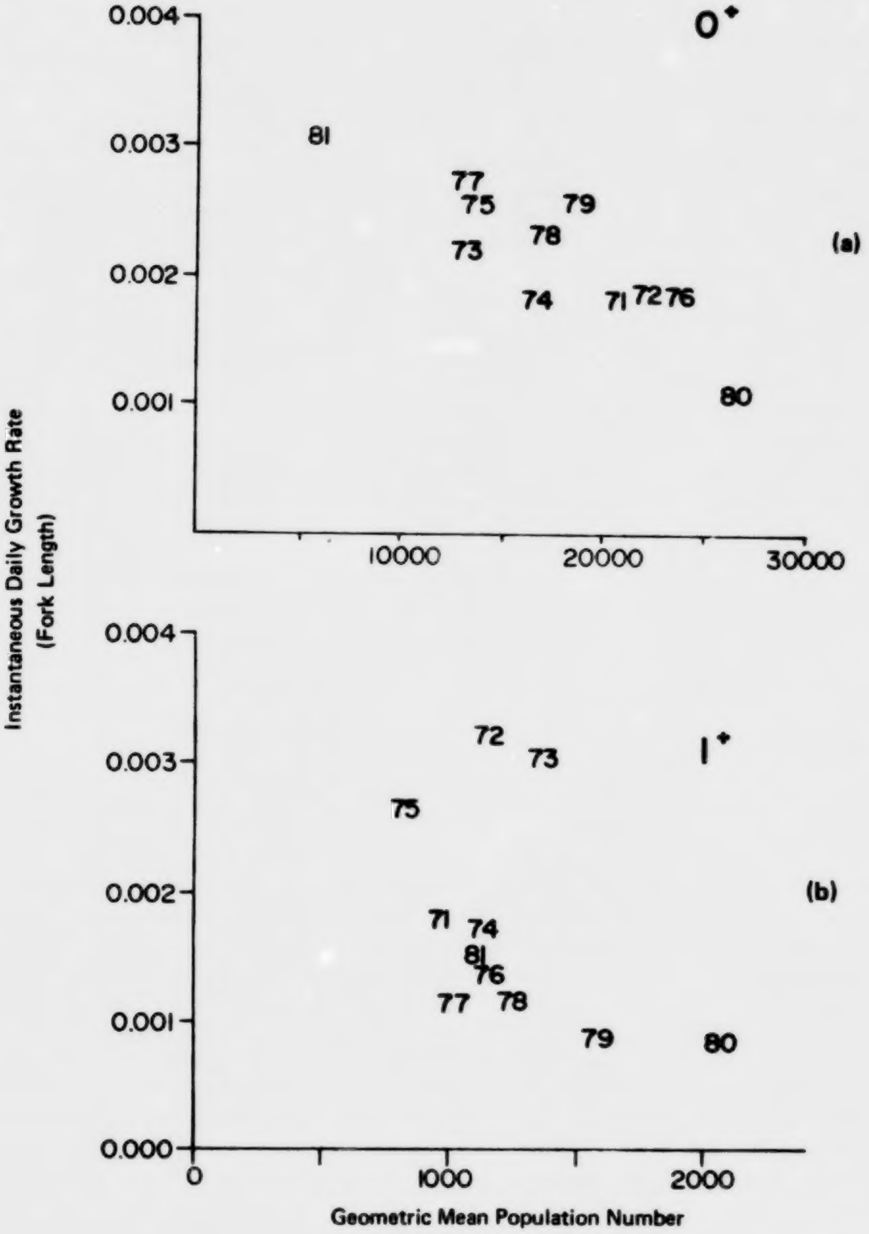

Fig. 9. Instantaneous daily growth rate in length during the summer for (a) coho fry (0+) and (b) coho yearlings (1+) as functions of geometric mean total population numbers.

Table 12. Regression for coho summer growth rates. Notation for independent variables, as per Table 6.

Dependent Variable	Fish Age	Independent Variable	Parameter[a] Estimate	Cumulative R^2
Instantaneous daily growth rate in fork length	0+	(intercept)	0.009955	--------
		density 0+ coho	–0.001985	0.684
		MNFLOW1	0.000052	0.697
		PTIME1	–0.002516	0.837
	1+	(intercept)	–0.000675	--------
		PVEG	0.001205	0.459
		PTIME1	0.004465	0.636
Instantaneous daily growth rate in weight	0+	(intercept)	0.04542	--------
		total coho density (0+ + 1+)	–0.008747	0.672
		PCUT	–0.003497	0.836
	1+	(intercept)	0.001582	--------
		PTIME1	0.01802	0.609
		PVEG	0.003463	0.770

[a] All significant at least at 5% level.

For 1+ fish, 66.7% of the growth rates can be explained by a model incorporating two variables (Table 12). As noted previously, growth rates of 1+ fish were not density-dependent. The growth rate increased with increases in the proportion of streambank that was vegetated. In general, growth rates of 1+ fish were higher prior to logging. Growth rates decrease with greater probabilities of low-flow events. A similar relationship was found for the 0+ fish. Again, we would suggest that low flows cause reductions in the rate of food supply and adversely affect growth.

Summer growth rates in weight were also analyzed. Unlike growth rates in length, growth rates in weight for 0+ fish show no significant trends with time, although there is considerable variability (Fig. 10a, Table 11). There was, however, a marked decline with time of the weight growth rates of 1+ fish (Table 11). As with length, weight growth rates were highly density-dependent for the 0+ fish but were density-independent for the 1+ fish.

Multiple regression models predicting weight growth rates for the 0+ fish were different from those predicting length growth rates (Table 12); 83.6% of the variance was explained by two variables. Growth rates decreased with increasing density and decreased as an increasing proportion of the streambank was logged. Flow regimes were not important in predicting weight growth rates, as they were in the prediction of length growth rates. For the 1+ fish, the predictive equation for weight growth rate incorporates the same variables as the equation for length growth rate.

In addition to density, two types of variables are important in predicting growth rates: the frequency or duration of low flows; and the extent to which the streambank has been altered by logging. Both variable types have implications for species such as coho which are drift or surface feeders.

Growth rates for weight and length are not interchangeable. For 1+ fish, weight growth rates are 3X length growth, rates with little variability (r = 0.977,

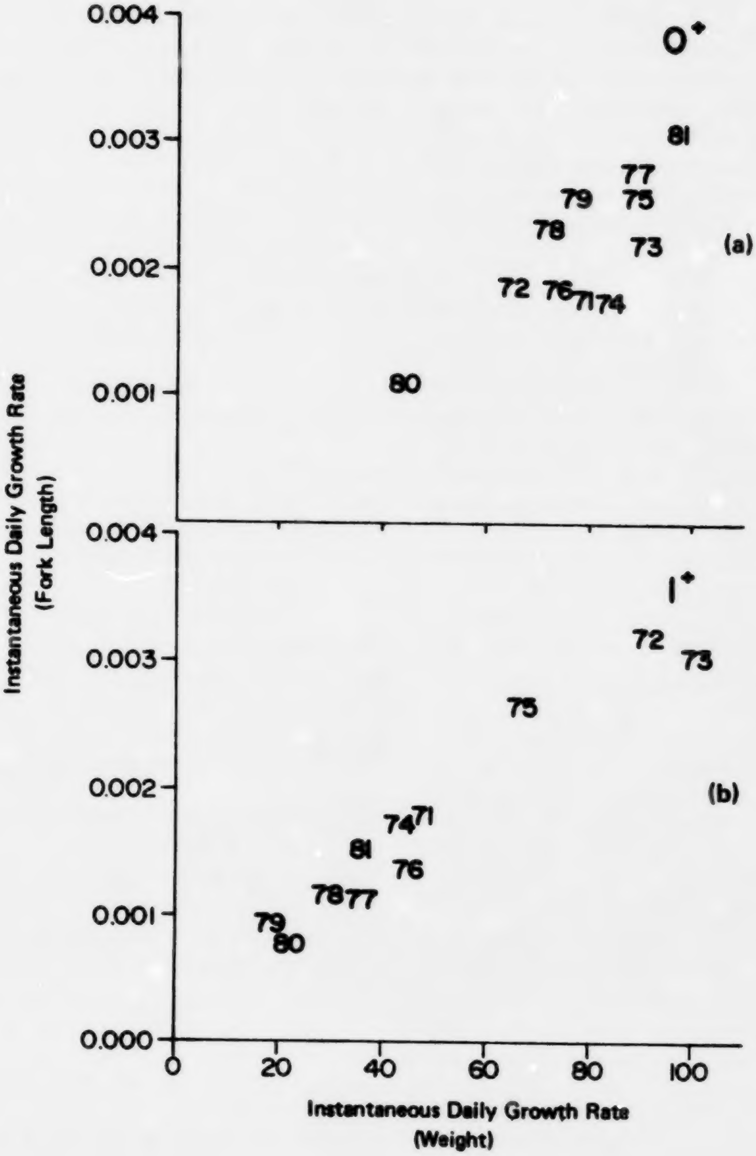

Fig. 10. Instantaneous daily growth rates in length versus instantaneous daily growth rates in weight over the summer for (a) coho fry (0+) and (b) yearlings (1+).

$p << 0.001$) (Fig. 10b); for each centimetre of growth in length $\approx 1\ cm^3$ of volume is added. For 0+ fish, the same ratio varies from 3.04 to 4.27. In general, the ratio of growth rates decreases as the size of the fish entering the summer increases (Fig. 10b). For small fish, weight growth rates are higher than length. This is a common pattern of growth for salmonid fry (M.C. Healey, pers. comm.). The falling values of the ratio in the years during logging (relatively slower weight growth rates after logging) are due to the early emergence of fry (Hartman et al. 1982). By June 1, most of the fry had completed the rapid weight growth period.

The productivity of coho streams over large geographical areas is known to be dependent on summer minimum flows (e.g., Mathews and Olson 1980). The prevailing wisdom is that productivity is actually limited by the minimum available habitat space for the stream-rearing juveniles, which is expected to be a correlate of the minimum stream discharge (Newcombe 1981). In Carnation Creek, summer loss rates are not correlated with low-flow events (Tables 7 and 8a, b). Summer growth rates (Table 12) and end-of-summer numbers and biomass (Table 14) are correlated with the durations of low-flow events, but not with the magnitude of summer minimum flow.

While this is ostensibly consistent with the idea that available habitat is limiting to coho and that it is determined by flow level, there is good evidence that this is not the case in Carnation Creek. A regression between total wetted area and flow (Table 13) indicates that a doubling of wetted area requires approximately a twenty-fivefold increase in flow. Such extreme variation in minimum flows does not occur. However, riffle area is more sensitive to variations in minimum flow (Table 13). A sixfold increase in flow (from 1 to 6 cfs) produces a 1.65X increase in riffle area. Juvenile coho are drift feeders (Mundie 1969, 1971). Benthic production occurs predominantly in riffles, so changes in riffle area could be expected to change production rates of the benthos and affects rates of food supply to the fish. Decreased flow rates also decrease the drifting rates of benthic invertebrates (Waters 1969), so that under conditions of low flow, the rate of food supply to the pool-dwelling coho would be further restricted. We would suggest, therefore, that the correlations between low-flow events and coho growth and between summer numbers and biomass are due to the effects of low flows on the production and rate of supply of the benthic invertebrate food of the coho.

End-of-Summer Biomass and Population Size

End-of-summer biomass (or carrying capacity; Burns 1971) is a convenient measure of the capacity of a stream to produce fish. Smolt production, a more useful measure of stream production, is much more difficult to measure.

Total coho biomass was estimated for September 1 using summer mortality and growth relationships (described elsewhere). Biomass is expressed per kilometre of main creek; side channels and habitable tributaries have not been included.

Total biomass has ranged from 5.01 kg/km (1973) to 14.11 kg/km (1980) (Table 14), a 2.8X variation. Total numbers have ranged from 6 139 (1981) to 23 280 (1980) (Table 14), a 3.79X variation. The larger variation in numbers than in biomass is consistent with the density dependence of coho growth,

Table 13. Regression of total wetted area, pool area, and riffle areas on flow (during the summer, flow was measured at B-weir in units of cubic feet per second. Areas are in m^2. N = 23).

Total wetted area = 0.1798 X flow + 4.1402	r = 0.72
Pool area = 0.1205 X flow + 4.0801	r = 0.57
Riffle area = 0.4806 X flow + 3.2437	r = 0.71

Table 14. End-of-summer (September 1) biomass and population size for Carnation Creek coho.

Year	Number Per Kilometre			Kilograms Per Kilometre		
	0+	1+	Total	0+	1+	Total
1971	11 829	1 286	13 115	9.12	1.43	10.55
1972	8 932	669	9 601	5.44	2.79	8.23
1973	8 897	1 218	10 115	3.52	1.49	5.01
1974	12 652	1 113	13 765	4.33	2.10	6.43
1975	11 554	1 312	12 866	5.53	1.94	7.47
1976	13 280	1 225	14 505	6.35	2.12	8.47
1977	10 976	1 197	12 173	5.48	1.92	7.40
1978	11 990	1 117	13 107	8.34	2.36	10.70
1979	13 592	1 551	15 143	9.28	2.89	12.17
1980	21 138	2 142	23 280	10.36	3.75	14.11
1981	5 455	685	6 140	6.01	1.42	7.43

as shown previously. However, excluding 1980 and 1981, total numbers have ranged from 9 602 (1972) to 15 143 (1979), only a 1.57X variation; while over the same period, biomass varied 2.43X.

The usual interpretation of constant end-of-summer numbers is that the territorial behavior of juveniles limits the number of individuals that can be accommodated in a fixed area (Burns 1971). Assuming that the initial numbers are sufficient to more than saturate the available habitat, variability in numbers should be strongly related to variation in available habitat space and to changes in habitat quality.

The low *initial* population in 1981 (8 527 total population, May 21, 1981) was considerably below the end-of-summer populations in all other years (Table 14), indicating that the assumption of initial saturation was not met. Consequently, this year is excluded from this analysis. A multiple regression analysis with the end-of-summer population numbers for 1971 to 1980 was done using the independent variable sets used in the analyses of summer loss (Table 6). Variables included measures of summer temperature and flow conditions and indices of logging activity. In addition, estimates of riffle and pool surface areas at the time of minimum flow were used.

For end-of-summer numbers, 86.3% of the variation was explained by a regression of three variables (Table 15). Population size increased as the probability of flows less than 0.2831 m^3/s decreased. Summer minimum flow, the occurrence of more severe flow reductions, and measures of available habitat space on the day of minimum flow were not strongly correlated with population size. While hardly conclusive evidence, this suggests that the importance of low-flow events might not relate to the amount of physical habitat and territorial interactions but, rather, might be indicative of other processes related to flow regimes such as food delivery rates through invertebrate drift (Waters 1969).

End-of-summer numbers increased as the proportion of streambank was devegetated. This is probably indicative of a logging-induced increase in stream productivity that resulted from increased light penetration to the stream and to higher stream temperatures. It would be useful, however, to have more direct measures of the production of stream algae and invertebrates and to examine more closely the links between coho and other components of the stream biota.

The regression equation for prediction of end-of-summer biomass is similar to that for numbers

Table 15. Regressions for end-of-summer coho population size and standing crop in Carnation Creek. Notation for independent variables as per Tables 2 and 6.

Dependent Variable	Independent Variable	Parameter Estimate	Cumulative R^2
Log_{10} standing crop (kg/km)	(intercept)	2.46105	---------
	TMAX	0.68454	0.702
	MNFLOW2	−0.21979	0.855
Log_{10} population number	(intercept)	5.111527	---------
	MNFLOW2	−0.013221	0.504
	PVEG	−0.388187	0.728
	FLOWTEMP	−0.035356	0.863

(Table 15). The maximum temperature on the day of minimum flow explains 70.2% of the variance in end-of-summer biomass, with biomass increasing with maximum temperature. Although the maximum temperature and the proportion of streambank vegetated are not highly correlated, the inclusion of either variable in these regressions can (cautiously) be interpreted as indicative of the positive impacts that logging has had on stream productivity and ultimately on coho growth.

An alternative explanation lies in the relationship between summer temperatures and the length of the growing season. If the beginning of the growing season for young-of-the-year coho is taken at the time of 50% emergence, then there is a good relationship between length of the growing season and the end-of-summer biomass. Hartman et al. (in press) have shown that early emergence is an important factor in the larger fall sizes attained by coho fry. It is highly likely that both earlier emergence (i.e., on growth) and enhanced summer growth have contributed to increased end-of-summer coho biomass in Carnation Creek.

Smolt Production

Carnation Creek produces coho smolts that have spent 1, 2, and occasionally 3 summers in the creek. The proportion that are 1+ smolts has risen markedly since the inception of logging (Table 16; Fig. 11). The changing proportions are largely due to increased numbers of 1+ smolts. Numbers of 2+ smolts have been highly variable but have generally declined in the years since logging began. Total smolt numbers have increased from a prelogging mean total number of 2 384.4 (1971 to 1977) to a during-logging mean of 4 066 (1978 to 1982), an increase of 1.71X (Table 16).

After an initial decline from 1971 to 1977 and a period of relative constancy (1972 to 1976), the lengths and weights of both 1+ and 2+ smolts have increased from 1977 to present. The increased size of smolts could be expected from the increased size of 0+ and 1+ fish as they entered the winter (Table 10), but the numbers in the last 2 years (1981, 1982) are lower than those early in the study (1972, 1973).

Since 1977, the smolt yield (kg/km) of 1+ smolts produced has increased approximately threefold over what was essentially a constant prelogging production (Table 16). Production of 2+ smolts is variable, but there are no apparent trends, reduced numbers having been roughly balanced by increasing size. Total weight of smolt production (Fig. 11c, Table 16) has approximately doubled from the prelogging average, reflecting the increased size and abundance of 1+ smolts.

Total numbers of smolts produced by Carnation Creek are not atypical of west coast streams and rivers when compared on the basis of production per unit length (Table 17). However, the increase in production that has occurred since the beginning of logging is encompassed by the observed levels of between-stream variation.

Table 16. Coho smolt production from Carnation Creek. The date of smolt emigration is for 1+ and 2+ smolts combined.

Year of Smolt Emigration	Median Julian Date of Emigration	Smolt Age								
		1+				2+				
		Number	Mean Fork Length (cm)	Mean Weight (g)	Yield (kg/km)	Number	Mean Fork Length (cm)	Mean Weight (g)	Yield (kg/km)	Total Yield (kg/km)
1971	134	1 062	3.77	71.5	1.304	1 415	9.19	96.3	4.236	5.540
1972	125	1 346	5.90	82.9	2.587	574	11.99	106.0	2.242	4.829
1973	128	1 115	4.80	77.6	1.743	776	9.04	97.4	2.285	4.028
1974	129	1 214	4.53	74.1	1.791	1 444	10.55	99.2	4.962	6.754
1975	129	1 247	4.50	75.2	1.828	875	8.95	94.6	2.551	4.379
1976	131	1 995	4.02	73.0	2.612	1 068	8.20	92.8	2.853	5.465
1977	124	1 625	4.87	78.1	2.578	935	9.11	97.5	2.775	5.352
1978	122	3 868	5.98	83.6	7.534	778	10.30	100.0	2.610	10.145
1979	120	2 862	5.43	80.6	5.062	668	9.38	96.3	2.041	7.103
1980	121	3 576	6.34	85.4	7.385	991	11.46	104.6	3.699	11.084
1981	125	3 726	5.61	82.4	6.809	400	11.07	104.1	1.442	8.251
1982	126	2 839	7.00	88.0	6.473	622	11.10	105.0	2.249	8.722

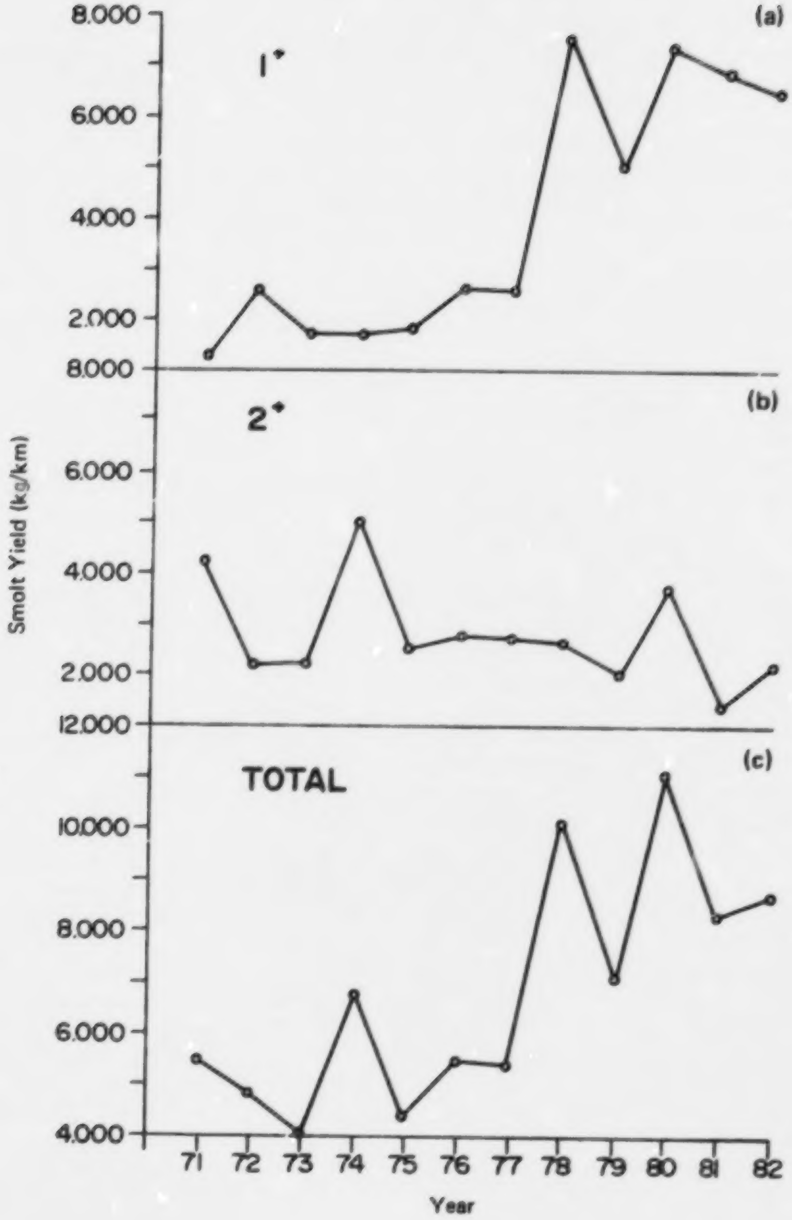

Fig. 11. Coho smolt yields from Carnation Creek for:

(a) 1+ smolts.
(b) 2+ smolts.
(c) Total smolt yield.

Based on data from west coast streams, Marshall and Britton (1980) developed predictive relationships for smolt yield based on stream length:

$$\text{yield (kg)} = 8.0359 \text{ X stream length (km)}^{1.3449}$$
$$\text{yield (no)} = 1134.3 \text{ X stream length (km)}^{1.1507}$$

In the prelogging period (1971 to 1976), the predictions overestimate the observed by factors of 2.3X (weight) and 1.74X (numbers) (Table 17). In the logging period 1977 to 1982, estimated smolt number is only 1.01X observed, but predicted weight is 1.31X observed. When weight per smolt is considered, predicted values are considerably higher than those observed in both periods. Smolts produced by Carnation Creek are apparently either small compared to those produced by some other coastal systems (compare with Moring and Lantz 1975) or disproportionate numbers leave as 1+ smolts (compare with Crone and Bond 1976). However, the size of juvenile coho in Carnation Creek is comparable to that of other Barkley Sound streams (Narver and Andersen 1974; Andersen and Narver 1975: Andersen 1978, 1981), and presumably, smolts produced by these

Table 17a. Smolt yields from other west coast streams. Data from Marshall and Britton (1980), G.D. Taylor, BCMOE (pers. comm.), and Crone and Bond (1976).

Creek/Stream/River	Length	Yield No./km
Dear Creek – prelogging	2.3	1 017
– postlogging	2.3	1 025
Flynn	1.3	678
Needle Branch	0.9	371
Keogh	35.0	1 857
Minter	16.7	1 704
Qualicum	12.9	2 374
Qualicum main stem	10.5	3 018
Hunts	2.4 to 5.2	1 826
Capilor	23.3	2 421
Cheakamus	15.1	2 561
Cowichan	55.2	2 771
Cowichan side tributaries	0.82	2 686
Postuet	3.30	1 157
Rible Camp side channels	1.21	2 376
Kelvin	11.42	1 224
Meign	3.2	1 761
Little Stawanus	3.7	1 800
Bonsall	11.2	1 413
Hooknose	2.9	1 719
Black	30.6	1 510
Salmon	17.4	2 430
Nile	5.6	888
Chet	5.7	2 562
Coglan	7.0	1 730
Lynn	5.5	540
Sashin	1.1	1 654
Carnation – 1971 to 1976	3.07	771.7
– 1977 to 1982	3.07	1 324.4

Table 17b. Predictions for Carnation Creek based on yield-stream length relationships of Marshall and Britton (1980).

	Predicted	Observed	Predicted/Observed
Yield (kg) – prelogging	36.32	15.76	2.3
– postlogging	36.32	27.82	1.31
Yield (no.) – prelogging	4 123.6	2 369	1.74
– postlogging	4 123.6	4 066	1.01
Weight (g)/smolt – prelogging	8.81	6.65	1.32
– postlogging	8.81	6.84	1.29

systems are similar in size to those produced by Carnation Creek.

Predictions of smolt production from more easily measured variables have received some attention as aids for the assessment of the productive capacity of streams. The most useful predictors have been various measures of flow and habitat space with flow invariably interpreted as a modifier of available habitat space.

Multiple regression models were developed to predict both smolt numbers per kilometre and total smolt weight per kilometre. The independent variable set included summer flow and temperature data and measures of logging activity along the streambanks, measures of habitat space at minimum flow, as already discussed in the sections on summer loss rates and end-of-summer biomass. Also included were measures of winter flow and temperature conditions, as discussed in the section on winter loss.

The number of smolts produced (1+ and 2+ combined) was best predicted by a model incorporating the variables: (1) summer thermal summation; (2) minimum winter temperature; and (3) maximum mean daily winter flow (Table 18).

Smolt yield increased with increasing summer and winter temperatures and decreased as maximum winter flows increased. Increased summer temperatures were a direct consequence of logging and are correlated with both increased numbers (Holtby and Newcombe, these proceedings) and sizes of fish entering the winter (see section on end-of-summer biomass). Increased numbers and sizes of juveniles entering the winter tended to increase the numbers of fish surviving the winter and, hence, increased the number of smolts produced. Favorable winter conditions, characterized by warm temperatures and low maximum flows, also led to higher smolt yield.

The total weight of smolts produced is predicted by a similar regression equation (Table 18). Smolt yield increases with summer temperature summations and decreases with maximum mean daily winter flow. In this regression, minimum winter temperature is replaced by total summer discharge, with smolt yield decreasing as summer discharge increased. This probably reflects the negative effects of summer storms and high summer flows on the growth rates of 0+ and 1+ fish (see section of summer growth).

Burns (1971) describes a method for comparing stream productivity based on measurements of biomass at the end of the summer or during the period of minimum flow (i.e., the time of minimum habitat space). This approach is used by the Fish Habitat Improvement Section of B.C. Fish and Wildlife Branch, Ministry of Environment (G.D. Taylor, pers. comm.). This methodology is seriously compromised by variable and often large winter mortality (Bustard and Narver 1975; Tschaplinski and Hartman, in press; Mason 1976; Marshall and Britton 1980) which weakens correlations between end-of-summer biomass or numbers and smolt yield. In this study, adding information about end-of-summer numbers or biomass to the above regressions *decreased* the explained variance of the models, indicating that, with highly variable year-to-year winter conditions,

Table 18. Regressions for coho smolt yield from Carnation Creek.

Dependent Variable	Independent Variable	Parameter Estimate	Cumulative R^2
Smolt number per metre	(intercept)	0.5435	-------
	summer thermal summation (°C days)	0.00201	0.544
	min. winter temperature (°C)	0.1606	0.745
	$\log_{10}$ max. mean daily winter flow (cfs)	−1.0231	0.857
Smolt weight (kg/km)	(intercept)	0.01148	-------
	summer thermal summation (°C days)	0.00001798	-------
	$\log_{10}$ max. mean daily winter flow (cfs)	−0.01029	0.795
	total flow Nov. 1 to Mar. 31 (cf X 10^8)	−0.00275	0.917

Table 19. Numbers of adult coho returning to Carnation Creek. Male totals exclude jacks.

	Smolt Age							
	1+				2+			
Year of Smolt Emigration	No. of Smolts	Males	Jacks	Females	No. of Smolts	Males	Jacks	Females
1971	1 062	60	33	39	1 415	27	29	36
1972	1 346	66	49	62	574	23	27	13
1973	1 115	46	21	26	776	26	22	40
1974	1 214	46	23	27	1 444	43	52	42
1975	1 247	42	29	22	874	26	25	33
1976	1 995	43	11	25	1 068	33	24	26
1977	1 625	30	13	34	935	16	40	22
1978	3 868	125	186	148	778	11	47	28
1979	2 862	99	85	63	668	21	29	8
1980	3 576	51	70	26	991	19	31	12
1981	3 726	-----	44	-----	400	—	23	—

smolt yield is at best weakly linked to the numbers on total biomass of juveniles in the stream at the end of the preceding summer.

Adults

Procedures employed for trapping and ageing adults are described in Narver and Andersen (1974).

Years referred to below are years of smolt emigration. Jacks return in the fall of the year of emigration. Males and females return, without exception, the following fall. Unless explicitly stated otherwise, references to male fish exclude jacks.

Total numbers of adults returning from specific smolt years ranged from 155 (1977 smolts) to 545 (1978 smolts), with a mean of 244 (n = 10; Table 19). Total numbers of jacks returning fluctuated between 35 and 76 (mean 56.9) from 1971 to 1977. Two hundred and thirty-tree jacks returned from 1978 smolts, 4.09X the previous mean. Returns from 1979 to 1981 smolts remained above the 1971 to 1977 mean. Total male returns from 1971 to 1974 were constant (mean 86.8, range 82 to 89), but declined to 46 by 1977 (Table 19). There were marked increases in 1978 and 1979 smolt-year returns (maximum 136, 1978). Preliminary returns for 1980 smolts are 70, a return comparable to prelogging figures. Female returns show similar trends to males, except that only the 1978 smolt year produced large returns. Returns for 1979 were comparable to prelogging returns, but returns for 1980 (26 + 12) were the lowest observed to date.

As noted previously, smolt counts for 1971 are thought to be underestimates due to the inability of the temporary fence used in that year to sample during moderate to high flows. The magnitude of the possible error is unknown.

Marine Return Rates

Percentage marine survival can be estimated by dividing total returning adults by smolt production. Since all adults are aged on return, their smolt year is known. Survivorship can also be portioned between 1+ and 2+ smolts. Such estimates are *minimum* estimates of marine survival, since losses to the fishery are not known. Overall returns (including jacks) have been from 3.92% (1980) to 12.5% (1972), with a mean survival of 8.44%. Excluding jacks, returns have ranged from 2.50% (1980) to 8.54% (1972), with a mean survival of 5.74%.

On average, 2+ smolts have had a negligible survival advantage compared with 1+ smolts (jacks excluded). The ratio of survival 2+/survival 1+ ranges from 0.660 (1972) to 1.621 (1976), with a mean of 1.019 (Table 20). However, on average, 2.29X the number of 2+ smolts returned as jacks, as did 1+ smolts.

An average return rate of 5.74% is 3.7X the average return rate of Puget Sound hatchery coho (Mathews and Olson 1980). This could mean that marine survival of Carnation Creek fish is correspondingly higher or, more likely, that the fishery on Carnation Creek coho is much less intense than on Puget Sound fish. Commercial fisheries terminate 2 months before the majority of adults enter Carnation Creek in late October.

Bilton et al. (1982) present relationships between percent returns (including the fishery) and the size and time of release of hatchery coho smolts. We applied these models to the Carnation Creek smolt data using mean smolt weights and the date of 50% completion of the smolt run. For all adults including jacks, the model of Bilton et al. (1982) predicts returns of 12.4% and 13.6% for 1+ and 2+ smolts, averaged over 10 years. Predicted returns emerged from 9.95% to 15.7% for 1+ smolts and from 10.7% to 16.7% for 2+ smolts. Observed returns ranged from 3.5% to 13.2% for 1+ smolts and from 5.3% to 11.3% for 2+ smolts with mean returns of 8.3% and 8.9% (Table 20). The ratios of predicted/observed percent returns averaged 1.49 and 1.52 for 1+ and 2+ smolts.

For adults excluding jacks, predicted returns are 11.9% and 13.2% for 1+ and 2+ smolts, while observed returns are 5.0% and 5.4%. Predicted returns of jacks were 0.323% and 0.449% for 1+ and 2+ smolts. Observed returns were 4.4% and 7.4%, 13.7X and 16.5X greater than the predicted returns.

Model predictions for adults, both excluding jacks and for jacks alone, generally were for lower returns in late years. This is especially true for 2+ smolts. Predictions of lower returns were due to earlier dates of out-migration for 1+ smolts and earlier migration dates, and consequent lower predicted returns were somewhat compensated by larger size in later years. For 2+ smolts whose size increased very little during the study, earlier out-migration led to a marked decline in predicted survival.

Relationships between observed and predicted returns are weak, however. For jacks, correlation coefficients were near zero; r = –0.253 and 0.007 for 1+ and 2+

Table 20. Observed (obs.) and predicted (pred.) returns at maturity for Carnation Creek coho. Jacks are excluded from "adult" returns. Predictions are made from published relationships (Bilton et al. 1982) based on smolt size and time of smolt emigration. A 1:1 sex ratio has been assumed for emigrating smolts.

Smolt Age	Year of Smolt Emigration	Females Obs.	Males Obs.	Adults		Jacks		Total	
				Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
1+	1971	7.34	11.30	9.32	15.26	6.21	0.371	12.43	15.70
	1972	9.21	9.81	9.51	11.10	7.28	0.315	13.15	11.36
	1973	4.66	10.04	7.35	12.98	3.77	0.355	9.24	13.34
	1974	4.45	7.58	6.01	13.41	3.80	0.360	7.91	13.78
	1975	3.53	6.74	5.13	4.76	4.65	0.328	7.46	12.07
	1976	2.51	4.31	3.41	13.38	1.10	0.358	3.96	13.76
	1977	4.18	3.69	3.94	10.69	1.60	0.294	4.74	10.94
	1978	7.65	6.46	7.06	10.42	9.62	0.289	11.87	10.65
	1979	4.40	6.92	5.66	9.76	5.94	0.252	8.63	9.95
	1980	1.62	2.91	2.27	10.45	2.52	0.293	3.52	10.68
	1981	-------	---------	-------	---------	2.36	0.335	---------	---------
2+	1971	5.09	3.82	4.45	16.24	4.10	0.453	6.50	16.69
	1972	4.53	8.01	6.27	14.70	9.41	0.613	10.98	15.28
	1973	10.31	6.70	8.51	13.36	5.67	0.430	11.34	13.74
	1974	5.82	5.96	5.89	14.46	7.20	0.511	9.49	14.93
	1975	7.55	5.95	6.75	15.19	5.72	0.443	9.61	15.62
	1976	4.87	6.18	5.52	14.14	4.49	0.414	7.77	14.53
	1977	4.71	3.42	4.06	12.14	8.56	0.409	8.34	12.48
	1978	7.20	2.83	5.01	10.54	12.08	0.404	11.05	10.85
	1979	2.40	6.29	4.34	10.43	8.68	0.358	8.68	10.68
	1980	2.83	3.83	3.33	10.40	4.04	0.469	5.35	10.76
	1981	------	---------	-------	---------	11.50	0.439	---------	---------

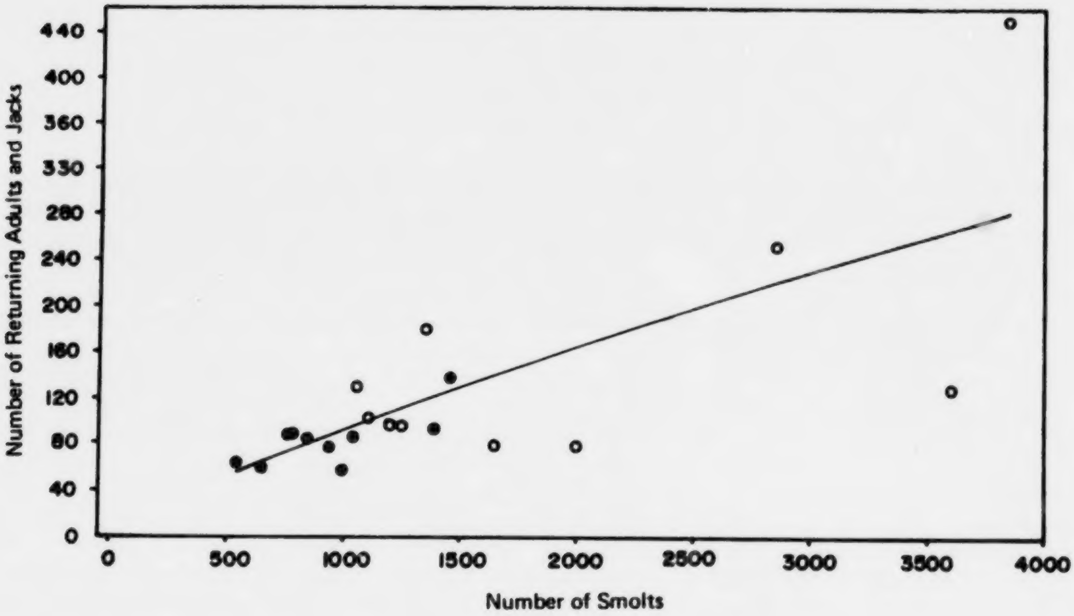

Fig. 12. Total coho adult returns including jacks as a function of number of smolts produced (0 – 1+ smolts; 0 – 2+ smolts). The solid line is the fitted nonlinear regression line (see Table 21).

smolts. For adults excluding jacks, correlations between predicted and observed were 0.346 ($0.2 < p < 0.4$) and 0.461 ($0.1 < p < 0.2$) for 1+ and 2+ smolts, also statistically nonsignificant. Given the uncertain and probably variable extent of the commercial catch, lack of a good correlation between predicted and observed returns to the stream is not surprising. Note, however, that despite lower predicted percentage returns, increased numbers of smolts would make expected numbers of returns higher in the postlogging period.

Adult-Smolt Relationships

An important question that the Carnation Creek data section can address is whether increased smolt output increased adult returns. A plot of total adult returns (including jacks) versus smolt output (Fig. 12) suggests that there has been increased adult return with increased smolt output. The relationship:

$$\text{No. adults} = k_1 \text{ no. smolts } k^2$$

was fitted to the data using a Poisson error distribution. With this error distribution, variance in the dependent variable is expected to increase with increasing values of the independent variable. Use of such an error term has been shown by Peterman (1981) to be more consistent with adult return data than the more commonly used, normally distributed error term. A k_2 value in the equation of less than 1 indicates nonlinearity; proportionally smaller adult returns for increased smolt outputs. The k-value observed here of 0.875 is significantly less than 1 (t-test, $t = 24.8$, 18 df, $p << 0.001$), indicating nonlinearity in the adult-smolt relationship. Similar relationships were found for jacks, males, and females considered separately (Table 21).

In all cases, there is a highly significant correlation between the log transformed adult and smolt abundances. It may be concluded that the relationship between adult returns and smolt production is density-dependent (Peterman 1982).

Table 21. **Parameter estimates for nonlinear model relating adult returns to smolt output.**

	n	k_1	k_2[a]	Standard Error of Estimate
Female + male	20	0.207	0.875	0.0353
Female + male (excluding jacks)	20	0.168	0.848	0.0431
Female	20	0.0738	0.855	0.0619
Male (excluding jacks)	20	0.0979	0.838	0.0573
Jacks	22	0.1504	0.76602	0.05343

[a] All significantly < 1 at the 0.001 level.

Effects of Smolt Size On Marine Survival

The predation rate that smolts experience in early marine life is thought to be inversely related to their size (Healey 1982; Parker 1962). Smolt size and time of release have both been shown to be important factors in predicting returns of hatchery-raised coho (Bilton et al. 1982).

Effects of smolt size on survival were determined using an analysis of the residuals of the return versus smolt relationships discussed previously (Table 21). The curve fitted to these data describes the average relationship between numbers of returning adults and numbers of smolts. We reasoned that positive residuals (i.e., observed return-predicted return > 0) should be associated with larger smolt size or weight. Plots of residuals versus smolt weight (Fig. 13) indicate that, for 1+ smolts at least, returns increased with increasing smolt size. For 2+ smolts, residuals appear independent of smolt size.

For the hatchery-raised coho smolts released by Bilton et al. (1982), returns increased with increasing size of smolts well beyond the 11.5 g of the heaviest (on average) smolts leaving Carnation Creek. It is possible that increases in survivorship attributable to increased size for Carnation Creek 2+ smolts are too small to be detected; but that increased survivorship of a 6.5 g smolt as compared to a 4.5 g 1+ smolt was sufficiently large to be detected.

This analysis is confounded by time of smolt out-migration which has peaked earlier in the year since logging began. Assuming that higher survival results from later out-migration well into June (Bilton et al. 1982), then the observed trend toward earlier out-migration (Table 16) should have decreased survival. For 1+ smolts, the benefits of increased size apparently outweighed any detrimental effects of earlier out-migration. For 2+ smolts, however, it is possible that the benefits of larger size were nullified by the detrimental effects of earlier out-migration.

Sex Ratio of Returning Adults

The large returns of jacks to Carnation Creek suggest that consideration of the sex ratios of returning adults would be of some interest. Including jacks, sex ratios females/males averaged 0.428 for 1+ fish and 0.456 for 2+ fish (Table 22), both values being significantly less than 1 (t-tests: for 1+ fish, $t = 3.620$, 9 kf, $p < 0.01$; for 2+ fish, $t = 2.803$, 9 df, $p < 0.05$). Excluding jacks, female/male ratios averaged 0.721 for 1.1+ fish and 1.140 for 2.1+ fish. Neither value is significantly different from 1. For 1.1+ fish, this result is somewhat misleading, since in 8 of 10 years, the ratio is less than 1; and in 7 of these years, the observed ratio is less than the mean, indicating that there is a trend for more males than females to return from 1+ smolts. The sex ratio of returning 2.1+ fish is highly variable (range 0.381 to 2.545).

Given the considerable jack return, sex ratios of 1 or less indicate that female coho suffer higher mortalities than do males (assuming sex ratio of smolts is 1). Females are known to be exploited at higher

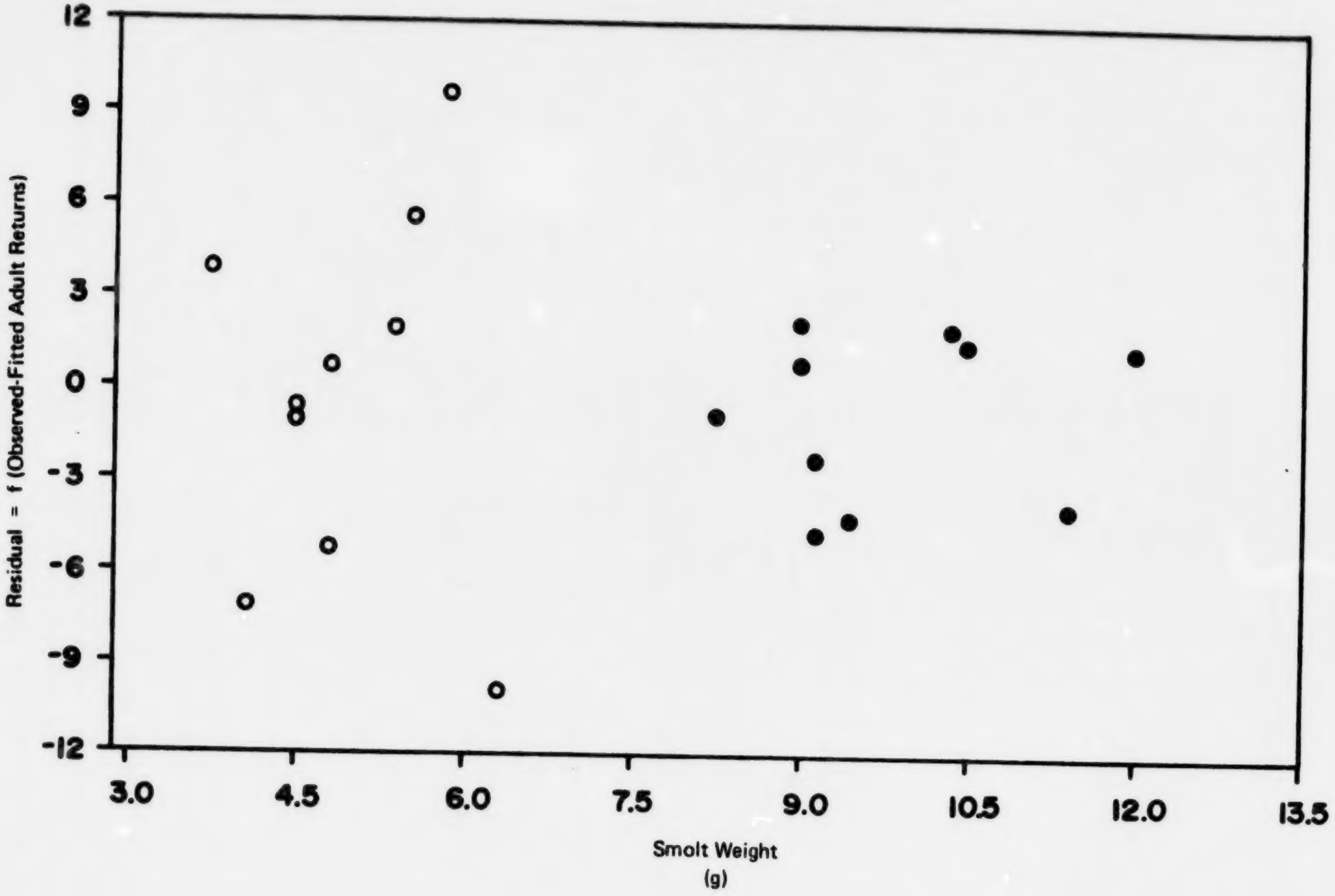

Fig. 13. Residuals of the adult return = f (smolt output) functions (see text and Table 21) versus smolt weight at time of outmigration (0 – 1+ smolts; 0 – 2+ smolts).

Table 22. Sex ratios of adults returning to Carnation Creek.

Year of Smolt Emigration	1.1+ Adults		2.1+ Adults	
	No. of Female/ No. of Male	No. of Female/ No. of Male + Jacks	No. of Female/ No. of Male	No. of Female/ No. of Male + Jacks
1971	0.650	0.419	1.333	0.643
1972	0.939	0.539	0.565	0.260
1973	0.464	0.338	1.538	0.833
1974	0.567	0.391	0.977	0.442
1975	0.524	0.310	1.269	0.647
1976	0.581	0.463	0.788	0.456
1977	1.133	0.791	1.375	0.393
1978	1.184	0.476	2.545	0.483
1979	0.636	0.342	0.381	0.160
1980	0.510	0.215	0.632	0.240

rates in the troll fishery (M.C. Healey, pers. comm.). The troll fishery is probably the major source of mortality on oceanic fish. Initial mortality may also be higher on females because female smolts are possibly smaller than male smolts (B.C. Andersen, pers. comm.). This explanation is supported somewhat by the different sex ratios shown by 1.1+ and 2.1+ adults (Table 22). On average, 1+ smolts produce lower female/male ratios than do 2+ smolts, which are larger smolts. For 1+ smolts, size is clearly correlated with high survivorship, which is not the case for 2+ smolts. If within the broad size range of 1+ smolts leaving within any year, males tended to be larger; male returns could be expected to be higher. The relative importance of any of these two potential differential sources of mortality are unknown.

Jacks

Jacks are precocious males that mature in the fall of the year they smolted. The total number of jacks returning to Carnation Creek has varied from 35 to 233 (Table 19). As noted previously, returns of jacks make up a large percentage of total returns. On average, 13.7X to 16.5X the return observed for hatchery-raised coho smolts of the same size (Bilton et al. 1982).

The proportion of males that return as jacks increases with smolt size for both 1+ and 2+ smolts. Proportionally, more jacks return from 2+ than from 1+ smolts, presumably because of their larger size. This size dependency is more marked for 1+ smolts. The maximum proportional return of 1+ smolts as jacks (0.58 to 0.60) is similar to the average proportional return for 2+ smolts (0.57). The overall proportions of males that return as jacks (0.468) has remained fairly constant with time (coefficient variation = 50.4%).

Why such a large proportion of jacks is found is a challenging problem. As speculation, we would suggest that large proportions of jacks should be found in populations where reproductive success is highly variable. The production of jacks, taken together with the production of 1+ and 2+ smolts, ensures that adults from a successful year would return for three following years. Without jack production, adults would return for 2 following years, and without production of two age-classes of smolts, adults would return for only one following year.

DISCUSSION AND SUMMARY

A useful understanding of how logging activities in the Carnation Creek watershed have affected the salmonid populations can only result from our elucidation of the processes which regulate the dynamics of the fish populations. Although the difficulties inherent in attempting a concise summary of the findings presented in this report are obvious, two important generalizations can be made about the nature of population regulation and the impacts of logging on the coho population in Carnation Creek.

First, Carnation Creek is not a productive system and the growth and survival of juvenile coho are food-limited. The importance of food to stream salmonids has long been recognized (Chapman 1966; Mason 1976). Stream productivity in the prelogging state was probably limited by a combination of low light, low temperatures, and low nutrient availability. Stream production ultimately determines the availability of food to stream fishes. Evidence that food limits of coho growth and survival come from the density dependence of growth and survival and the nature of other system variables that are predictive of growth or survival, the negative effects of low flows, the positive effects of streamside harvest, the positive effects of increased temperatures, etc., can all be related to food production or food delivery rates. The importance of food to stream salmonids has long been recognized (Chapman 1966; Mason 1976).

Second, the creek is not a hospitable environment during the winter. Winter mortality accounts for approximately 51% of the total mortality observed over the 1 or 2 years of stream residence. The severe winter flow regime of the creek is, in large part, responsible for the high mortalities. In addition, because winter mortality is dependent on fish size, mortality is strongly affected by growth conditions during the previous summer. Consequently, logging-related impacts on summer conditions have ramifications to late life stages.

Removal of the forest canopy through clear-cut logging has resulted in increased stream surface light levels, higher stream temperatures, and probably higher nutrient availability, all of which have led to increased stream productivity. The juvenile coho have shown a marked response to this presumed increase in stream productivity and stream temperatures. Higher winter temperatures since logging have caused earlier emergence of fry, resulting in a prolongation of the growing season. Higher growth rates in the postemergence period and over the first summer have increased the size of yearling coho entering their first winter, and lower summer mortalities have increased the numbers of yearlings entering the first winter. More large fish entering the winter have increased winter survival, resulting in greater numbers of large smolts leaving the creek at an earlier age. Two years later, more adults return. These positive effects of logging are, in all probability, transitory. Stream productivity can be expected to return to near prelogging levels within 12 to 15 years (Murphy and Hall 1981; Murphy et al. 1981).

Very significantly, however, streamside logging has led to gradual but accelerating changes in stream morphometry. Sedimentation and bedload movement associated with bank erosion and channelization have resulted from streambank logging practices and debris transport caused by logging activity. Such habitat degradation is implicated in already declining egg-to-fry survival. Continued degradation of habitat quality will eventually compromise the capacity of the stream to support overwinter survival. Further long-term damage to the productive capacity of Carnation Creek could result from the reduction or elimination of the supply of large organic debris.

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AN OVERVIEW OF SOME BIOPHYSICAL DETERMINANTS OF FISH PRODUCTION AND FISH POPULATION RESPONSES TO LOGGING IN CARNATION CREEK, BRITISH COLUMBIA

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INTRODUCTION

In the Carnation Creek Watershed Project, 11 years of work in the planned 15-year study are finished. The prelogging and logging phases are complete. The next few years of the study will involve monitoring the system to document postlogging responses. Even now, however, some responses in the system are evident, although the project is still in progress and all the results are not analyzed. The primary objective is to provide a brief synthesis of the most significant small stream processes which we have analyzed to date.

In the Carnation Creek watershed, the climate, soil, and topography determine both structural characteristics of the watershed and the regimes of stream temperature, discharge, and nutrient loading that drive the living systems which produce, what are to us, the end products of trees and fish.

This paper will attempt to summarize the initial effects of forest harvesting and management on the important stream processes that are relevant to fish production. It will attempt to relate, in part, how the processes of fish production and some changes within these processes are related to the thermal, hydrological, and nutrient regimes and to structural conditions in the watershed. Finally, the paper will discuss some ways in which managers might use the results of the Carnation Creek project to improve watershed management in regard to forest harvest and fish production in small systems like Carnation Creek.

It is very important to recognize that the relationships in the Carnation Creek system that are presented and discussed have exceptions in that system. Relationships and processes described here will apply, in general, to other streams like Carnation Creek. They will not, however, form rigid examples of processes or relationships that apply without exception to all coastal streams. One of the most useful products of a study such as this is the understanding of forest watershed processes. As much as possible, forest and fishery managers should exercise this understanding of processes in conjunction with their own experience and local knowledge to make decisions about the array of situations with which they must work. The Carnation Creek work will serve managers more usefully if used as a strong guide, rather than a rigid set of recipes.

FOREST HARVEST: COMPLEX EFFECTS

When one considers the impacts of a complex process such as forest harvesting on fish populations, it is necessary to recognize that there are many different activities associated with timber removal. These include road construction, tree cutting on hillsides, streamside cutting, yarding, and postlogging treatment. Also, in a typical coastal stream, there are several species of fish, each with a series of different life stages that may be critical. Changes in conditions that may be detrimental to one species may not be to another species or, indeed, to the same species at another stage.

In Carnation Creek, the various components of the forest harvest process generate their impacts on fish through alteration of several major regimes or conditions (Table 1). When considering these regimes or conditions, it is useful to recognize that, for each species of fish, there are optimum conditions within the total potential range of conditions. Figure 1, which embodies a concept developed by Mundie (pers. comm. 1981), illustrates this idea. It is important to understand that the effect of logging in a coastal watershed, such as Carnation Creek, may be a shift in conditions within the system into a more favorable range or, alternatively, into a range of extreme adverse effects.

Each of the six conditions or kinds of regimes listed in Table 1 is determined by complex sets of interactions between natural processes within the watershed. Specific activities in the logging process have the potential to alter both the underlying natural processes and their interactions and, thereby, alter stream conditions. The natural processes and the potential changes that are associated with forest harvest, which we consider important, are given for the six regimes or conditions in Carnation Creek (Tables 2 to 7). The details of changes observed have been dealt with in other papers in these proceedings. However, very brief statements about some of the most obvious changes in the system are also provided in Tables 2 to 7. These points are made to orient the reader; they are not intended as a substitute for the results presented in the background papers in these proceedings.

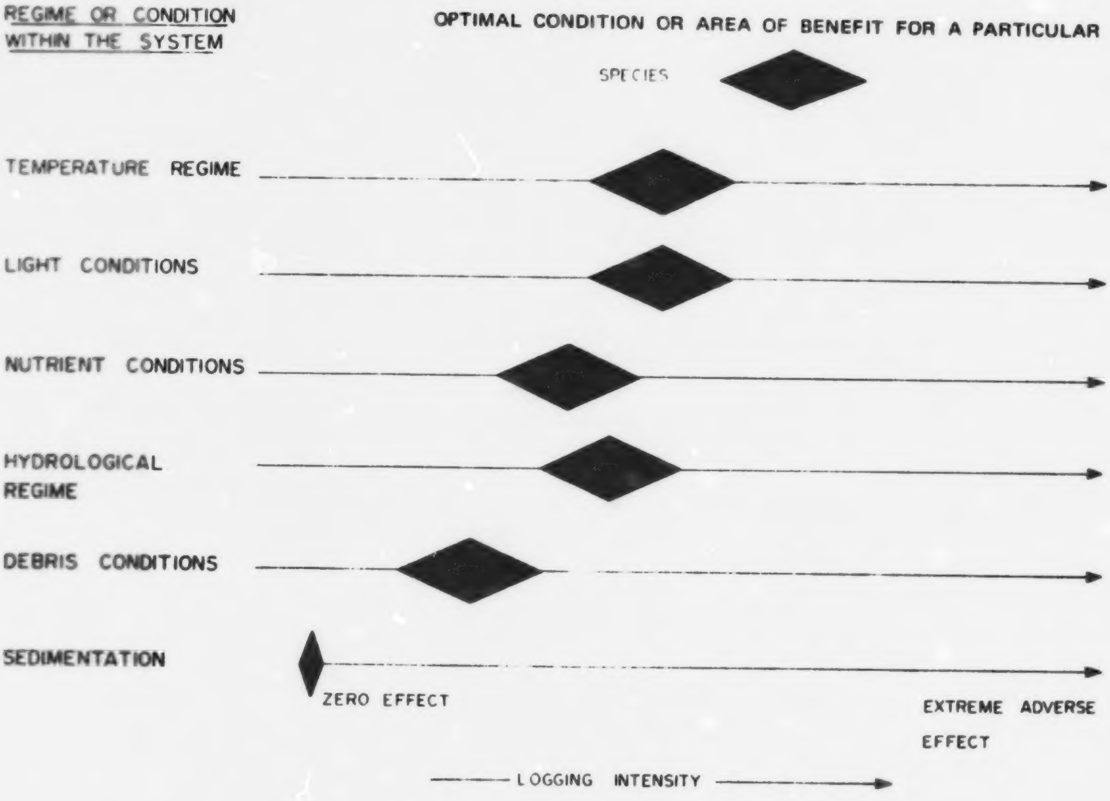
REGIME OR CONDITION WITHIN THE SYSTEM
OPTIMAL CONDITION OR AREA OF BENEFIT FOR A PARTICULAR SPECIES
TEMPERATURE REGIME
LIGHT CONDITIONS
NUTRIENT CONDITIONS
HYDROLOGICAL REGIME
DEBRIS CONDITIONS
SEDIMENTATION
ZERO EFFECT
EXTREME ADVERSE EFFECT
LOGGING INTENSITY

Fig. 1. A model of effects of logging activities on conditions within a watershed. In this case, logging intensity is considered to be increased by increasing the percent removal of trees, the sizes of clearcuts, the amount of streamside vegetation along the length of the stream, the amount of falling across and yarding out of or across the stream, area under road surface, and the amount of scarifying or burning after logging.

Table 1. Conditions in the Carnation Creek system which are altered by forest harvest and which have a major bearing on fish-population characteristics.

1. TEMPERATURE REGIMES
2. LIGHT CONDITIONS
3. NUTRIENT REGIMES
4. HYDROLOGICAL REGIMES
5. DEBRIS CONDITIONS
6. SEDIMENTATION

Table 2. The factors considered important in the natural determination of temperature regimes in Carnation Creek and the components of the logging process that accentuate natural effects.

TEMPERATURE REGIMES	
Natural Determination:	– Geological conditions. – Air temperature. – Direct sun.
Natural Effects Accentuated By:	– Streamside cutting. – Hillside cutting.
Observations:	1. Air temperature: partial control of stream temperatures, winter and summer. 2. Clearcut tributaries: summer temperatures up. 3. Main stem: higher summer temperatures; higher diel-temperature range. 4. Winter stream temperature higher after clearcutting and follows air temperature with time lag. 5. Summer-temperature changes: effects on growth potentially positive.

Table 3. The factors considered important in the natural determination of light conditions in Carnation Creek and the components of the logging process that accentuate natural effects.

LIGHT CONDITIONS

Natural Determination:
- Hours of daylight
- Cloud cover
- Topography
- Stream aspect
- Canopy

Natural Input Accentuated By:
- Canopy removal at streamside

Observations:

1. Higher illumination at stream level; a contribution to higher primary productivity; effects potentially positive.

Table 4. Factors considered important in the natural determination of nutrient regimes and components of the logging process that affect them.

NUTRIENT REGIMES

Natural Determination:
- Ions in with rain
- Vegetation decomposition
- Soil nutrient release
- Weathering bedrock

Natural Input Increased By:
- Soil disturbance:
  - roads
  - yarding
  - postlogging treatment
- Change in vegetative structure:
  - tree removal (conifers)

Observations:

1. Most ions strong inverse relationship to flow.

2. Same after logging with higher concentrations.

3. Phosphates low concentration not related to streamflow.

4. Nutrient increase; effects potentially positive.

Table 5. The factors considered important in the natural determination of hydrological regimes and the components of the logging process that alter natural effects.

HYDROLOGICAL REGIMES

Natural Determination:

- Precipitation:
  - volume
  - timing
  - rain-snow ratio
- Soil conditions
- Evapotranspiration rates

Natural Regimes Changed By:

- Tree removal
- Soil compaction
- Road construction
- Ditching
- Direction of yarding

Observations:

1. Rapid slope-water transport in porcus soils and macrochannels.
2. Valley-bottom groundwater higher in areas logged and scarified.
3. Winters 1976-1977 to 1979-1980; fewer and less severe storm events.
4. No clear evidence of change in annual water yield or in storm hydrograph peakflow or time-to-peak characteristics in the main creek.
5. In small clearcut northside tributary, annual yield and summer low flows are up.

Table 6. The factors considered important in the natural determination of debris conditions and the logging processes that may affect these conditions.

DEBRIS CONDITIONS	
Natural Determination:	– Streamside vegetation: · growth, falldown, and movement – Channel shape and structure – Hydrological regimes
Natural Input Volume and Stability Changed By:	– Streamside cutting.
Observations:	1. Volume and stability of debris reduced in areas clearcut to bank and cross-stream yarded. 2. Volume and stability of debris high in leave-strip areas. 3. Small debris produced in intensive treatment areas unstable in storms; negative effect. 4. Large debris armors banks and maintains variable channel form. 5. Reduced cross-sectional area in most of the channel.

Table 7. Factors considered important in the natural determination of sediment regimes and logging processes that accentuate sediment entrainment and deposition.

SEDIMENTATION	
Natural Determination:	– Precipitation – Soil type – Soil depth – Slope – Meteorological events
Natural Loading Increased By:	– Roads – Cutting – Postlogging treatments: · fire · scarification
Observations:	1. Coarse sand increased in top layer of gravel. 2. Main effect in lower 2 km of creek. 3. Most fine sand and silt is probably flushed completely out. 4. Quantities of sediment from different sources not determined; however, streambank erosion is considered to be a primary source.

To this point, it has been suggested that there is an array of different impacts in the watershed as a result of various activities in the overall forest harvest process. Furthermore, there are a series of stages through which each fish species may pass before it leaves the stream to begin ocean life. The various environmental changes that we have discussed will have different implications to fish of different species and to different life stages within each species.

LIFE STAGES OF SALMONIDS

Figure 2 illustrates the life stages through which a salmonid, such as coho or steelhead, may pass in completing one full generation of its life. A species that has a long and complex early life history in fresh water will pass through all or most of the following stages (Fig. 2). In each of these stages, there are critical requirements or pressures that the fish faces. The stages are:

1. Egg deposition.
2. Egg-to-fry survival: first-winter or winter-spring period. (Pink and chum fry and some coho fry leave the stream after this stage.)
3. First summer in the stream: 0+ age fry.
4. First winter in the stream: 0+ age fry.
5. Seaward migration of some 1+ age coho as smolts.
6. Second summer season in the stream: 1+ age fingerlings which have not left as smolts.
7. Second winter in the stream: 1+ age fingerlings.
8. Seaward migration of smolts; virtually all remaining coho leave at this stage in Carnation Creek.
9. Third summer season in the stream: 2+ age fish.
10. Third winter in the stream: 2+ age fish.
11. Fourth summer season in the stream. (Some trout may go to sea at this stage; others may remain one year longer or, if cutthroat, some complete their life cycle in the stream.)
12. Ocean life.
13. Entry into the stream: lower reaches.
14. Movement back to upstream spawning areas and egg deposition by adults.

The following species of salmonids inhabit Carnation Creek. Their life in the creek includes the stages from the previous list, indicated by numbers. (During 1982, a few sockeye and spring salmon entered the stream.)

Pink salmon
(occasional) – stages 1, 2, 13, and 14
Chum salmon – stages 1, 2, 13, and 14
Coho salmon – stages 1 to 8 and 13 and 14
Steelhead trout – stages 1 to 11 and 13 and 14
Cutthroat trout – stages 1 to 11 or
stages 1 to 11 and 13 and 14

EFFECTS OF STREAM CONDITIONS AT DIFFERENT LIFE STAGES

The following sections of this paper will consider the implications of the observed changes in each of the six major regimes or conditions (temperature, light, nutrients, hydrological, debris, and sedimentation) with regard to the freshwater life stages of coho. Although, initially, we will consider the regimes or conditions separately, it is important at all times to recognize that the fish are responding to simultaneous changes in all of the stream conditions. If, for instance, summer growth rates of trout and coho have been increased since logging, such an increase may ultimately be the compound effect of temperature, light, and nutrient regimes all changing. As another example, fish responses to changes in sediment regimes and debris conditions are, indirectly, responses to hydrological regimes. Recognizing this, we still will first consider the impacts of changes in each of the six single regimes or conditions on key freshwater stages in the life history of coho. If it is thought that there is no effect on fish resulting from changes in a given environmental condition or if the appropriate information is not analyzed, the life stage will be omitted.

Following consideration of the effect of changes in individual environmental regimes or conditions (e.g., temperature, light, nutrients), this paper will present overall smolt and fry production data for trout and coho. It will attempt to relate single and interacting environmental conditions and changes to some of the major coho population changes within the system.

There is some danger in trying to make the following tentative, broad statements. There are great risks in generalizing. For instance, generalities tend to ignore the enormous variability inherent in complex natural systems. Most of the generalizations that we will make have exceptions, within the time frame of study, for which there is no ready explanation. There is also a danger that generalizations in this paper may be

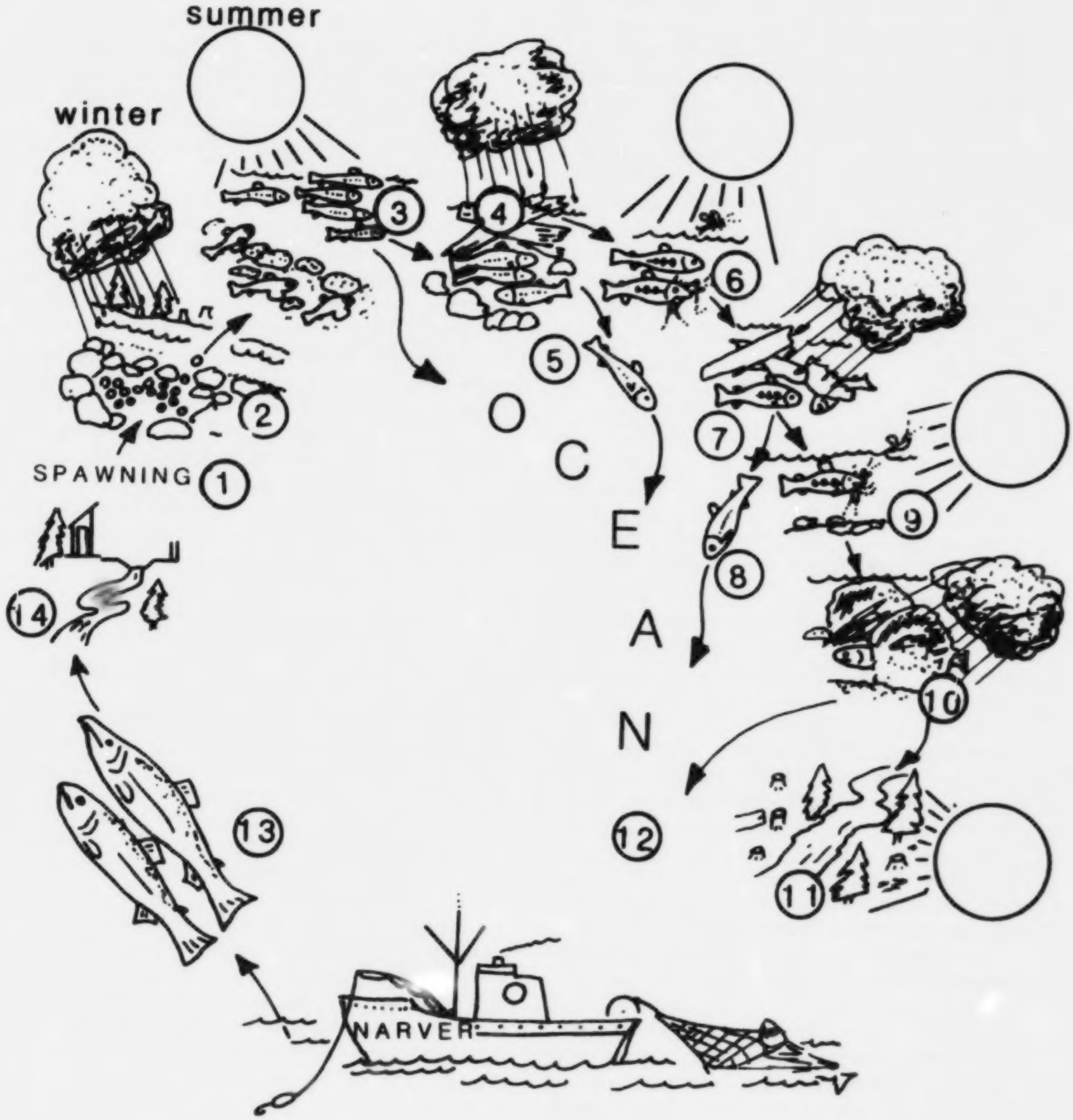
summer
winter
SPAWNING ①
②
③
④
⑤
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Fig. 2. The stage of life history and seasons through which a salmonid may pass in one complete life cycle. In fresh water, chum and pink salmon may pass through stages 1, 2, 3, 13, and 14; coho may pass through stages 1 to 8 and 13 and 14. Trout may pass through stages 1 to 10 and 13 and 14 or they may never leave the stream.

regarded as realities carved in stone. They are not. The following sections relate some of the major changes in stream conditions to the life-history stages which they effect. These sections may also indicate to the reader some of the complexities of watershed processes. Readers are referred to Holtby and Hartman (these proceedings) for an in-depth analysis of growth and survival responses of coho. That paper generates extensive correlations between growth rates, survival rates, and a range of environmental factors. It also indicates that elements other than those reviewed in this paper (e.g., amount of streamside vegetation, population density, and food delivery rates) can play an important role in the population dynamics of young coho salmon.

Temperature Regimes

Stage 2: Egg-to-Fry Survival

Winter temperatures in the main creek have been higher since the 1976-1977 season (Holtby and Newcombe, these proceedings). Some of this information is summarized by Hartman et al. (1982). The higher stream temperatures are strongly correlated with warmer air temperatures and are determined, in part, by them. However, since clearcutting began in the watershed, winter stream temperatures have been higher relative to air temperatures.

There appear to be three main results of higher winter stream temperatures. The incubation period has been shortened for coho. The fry emerge earlier. The fry begin spring-summer feeding and growing sooner. A preliminary review of the data presented by Narver and Andersen (1974), Andersen and Narver (1975), and Andersen (1978, 1981) indicates that the pattern of earlier emergence of chum fry above the counting fence, since the winter of 1975-1976, is similar to that of coho.

There are both positive and negative effects of a shortened incubation period. Early emergence of coho fry is an advantage for those fry that remain in the stream. They begin feeding and growing sooner. However, many fry that emerge early do so in a period of storms, in which they may be washed into the estuary or out of the system entirely.

Stage 3: Fry Growth and Survival
First Summer

Summer stream temperatures from 1977 onward have been higher and have tended to vary more throughout a daily 24-hour period (Holtby and Newcombe, these proceedings). Part, but not all, of this response is due to forest removal in the watershed. The changes are considered to have direct and indirect effects. Since logging, water temperature increases in summer in the main stem of the creek have not had much adverse effect on fish survival. Temperatures, which were measured in one small side tributary, did reach levels that were stressful to fish.

Stream temperature increases, along with nutrient and light increase, may have contributed directly to enhanced production of algae in the stream and indirectly to benthos production in the main stem. Although not specifically demonstrated, it has had the potential to contribute to the increased growth rate observed in trout (De Leeuw 1981) and, in some years, coho. Since 1976, coho fry have been larger on the average, when they enter their first winter in the stream. The early start of growth as a result of earlier emergence and warmer summer-temperature regimes contributes to this situation. The effects of all physical environmental conditions are masked, to some extent, by very strong density effects on fry growth in the first summer.

Stage 4: Fry Survival
First Winter

Correlation analysis does not indicate any clear relationship between higher overwinter survival (during and after logging) and higher stream temperatures.

Stage 6: Coho Growth and Survival
Second Summer—Fingerling Stage

The effects of stream-temperature changes, i.e., increases since logging, are considered to be potentially similar, at this stage, to the effects on first-summer fish regarding fry. Density-dependent factors, which tended to mask the effects of others among 0+ fry, do not appear to play a major role in determining growth of 1+ coho.

Stage 7: Coho Survival and Growth
Second Winter—Fingerling Stage

The effect of warmer stream temperatures on young coho during their second winter is not known. Population-estimate data indicate a progressive decline, from the early years of the study onward in overwinter survival of coho which are spending their second winter in the stream.

Stage 13: Entry of Adults Into the Stream
Following the Ocean Life Stage

High stream temperatures in autumn may play a role at this stage by inhibiting movement until temperatures fall.

Light Conditions

Work by Stockner and Shortreed (1976) demonstrated that clearcutting in the stream bottom would increase light intensities at the stream surface. Measurement of light on the stream by de Leeuw (1981) confirmed this. Primary production in the uncleared stream was considered to be partially limited as a result of low light intensities (Stockner and Shortreed 1976).

Stage 3: Fry Growth and Survival
First Summer

It is concluded that the effect of increasing light intensity at the stream surface by clearcutting has been to improve conditions for primary production.

The indirect effect of this on benthos production has the potential to be positive. We do not yet, however, understand particularly well the net effect of changes in conditions for primary production on one hand and of clearcut-related changes in leaf-litter input and, hence, detritus production on the other hand. In the uncut condition, streamside vegetation deposited about 31 metric tons of leaf litter per year in the stream. Anywhere from 50% to 75% of it remains in the stream (Neaves 1978).

Stage 4: Fry Growth and Survival
First Winter

It is not possible at this time to state what the effects of change in light intensity might have during the winter season. It may be important to determine whether or not bird and mammal predatory efficiency during winter is the same in open, higher light intensity, clearcut sections of streams as in heavily forested sections.

Stage 6: Coho Growth and Survival
Second Summer—Fingerling Stage

The effects of light-condition changes on fish at this stage are believed to be similar to those that apply to the fry stage.

Stage 7: Coho Growth and Survival
Second Winter—Fingerling Stage

It is unknown what the effect of increased light intensity might be on fish during this life stage. Fish, at this stage, show a strong tendency in winter to remain in darker areas of the stream in deep water and in areas of cover. Coho salmon in their second winter in the stream have undergone an increasing level of mortality during the past 5 or 6 years of the study. The possibility that increased light intensity has contributed to higher mortality through predation, at this stage as well as at the first-winter stage, merits consideration and is a potential topic for future study.

Nutrient Regimes

The work by Stockner and Shortreed (1976) indicates that, in the unlogged situation, nutrient loading was very low in the stream. Nutrient addition (phosphorus and nitrate) generated clear response in increased primary production (Stockner and Shortreed 1978). Scrivener, in these proceedings and in the 1979-1980 Carnation Creek Report (Hartman 1981), shows that overall concentration of most ions has increased during the period of logging and postlogging treatment. Both phosphate and nitrate have increased during the logging- and postlogging-treatment periods. The elevation of ion concentrations in the stream appears to be a short-term response.

Stage 3: Fry Growth and Survival
First Summer

Although linkages in all parts of the process are not established yet, nutrient-regime changes will have contributed to enhanced primary productivity and, indirectly, to benthic-organism production. The interpretation of the results at this stage of the work is that increased stream temperature during summer, higher stream-surface illumination, and increased nutrients act together positively to enhance production of algae and benthic organisms. The net effect of changes in primary production and changes in leaf-litter and detritus production has not been worked out fully at this stage of the study.

Hydrological Regimes

The major changes in hydrological conditions, logging-related and natural, are outlined in Table 2 and they have been dealt with in as much detail as possible at present by Hetherington (these proceedings).

At this stage of analyses, there is no clear evidence that clearcutting has caused changes in the relationship of runoff to precipitation or in the annual water yield in the total system. Water yield in one small tributary which was clearcut has been changed. The most significant changes in hydrological features are those associated with year-to-year changes in weather.

Stage 2: Egg-to-Fry Survival

Freshets and associated sediment transport and deposition determine egg-to-fry survival for both chum and coho salmon. Hydrological conditions determine bedload-movement and channel-form changes which may also contribute to the egg-to-fry survival declines noted. The decline in egg-to-fry survival has occurred during winters of reduced freshet severity. It is not possible to state what egg-to-fry survival rates may have been observed in more severe freshet conditions.

Stage 3: Fry Growth and Survival First Summer

Large numbers of coho fry move downstream in Carnation Creek in most freshets. This response, which is evident immediately after emergence, may be largely passive early in the spring. The effects of logging are considered to have been minor, with regard to the size and severity of floods and freshets. Natural patterns in numbers of early-spring coho fry moving seaward are not considered to be altered much by logging impacts manifested in hydrological-regime changes.

Summer-flow levels may be important determinants of growth, inasmuch as delivery rates of food may drop off at low flows (Holtby and Hartman, these proceedings).

Stage 4: Fry Growth and Survival First Winter

Young coho entering their first winter are displaced during autumn and early-winter storms and freshets. Natural patterns of movement have probably not been altered greatly as a consequence of logging impacts on hydrological regimes. However, discharge peaks, in association with unstable debris, dislocate fish and alter survival conditions for fish.

Stage 5: Seaward Movement of 1+ Age Coho As Smolts

Smolts frequently move in greatest numbers during summer freshets (Andersen and Narver 1975); Andersen 1978, 1981). However, movement is not exclusively related to freshets. Clearcutting does not, to date, have any apparent effect on hydrological regimes that might alter patterns of smolt movement.

Stage 6: Coho Growth and Survival Second Summer

Low flows during summer are considered to affect growth and numbers of coho by limiting the area in which benthic production can take place and by limiting the delivery rates of food.

Stage 7: Coho Growth and Survival Second Winter—Fingerling Stage

Many young coho in their second winter are displaced during autumn and early-winter freshets as a natural course of events. Natural rates of growth and overwinter survival are not considered to be affected as a result of logging changing hydrological conditions. However, where logging practices alter cover conditions (i.e., stable debris), natural unaltered freshets may have a more severe impact on distribution growth and in-stream survival of fish in the second winter.

Stage 13: Entry of Adults Into the Stream Following Ocean Life

Coho salmon enter the stream during freshets in fall and early winter. A delayed pattern of entrance appears to have occurred during autumn and early winter from 1977 to 1980. At this stage, we have no analysis that demonstrates changes in stream entrance related to changes in hydrology as a result of logging.

Debris Conditions

Clearcutting to the edge of the stream, streamside-alder removal, and falling trees across the stream, and yarding them from the stream all contribute to a reduction in the volume and stability of large debris (Toews and Moore 1982; these proceedings). Large debris refers to large chunks of tree trunk (i.e., over 3 m or 4 m long) and large root masses.

Large and stable debris plays a critical role in determining and maintaining bank stability and channel form in the stream. It plays a second critical role in providing cover for young fish that remain in the main stem of the creek during winter periods. Breakdown and erosion of banks, sediment release, and change in channel form are indirect effects of changes in debris volume and stability. In portions of Sections V, VI, and VII which were logged to the bank and across which falling and some yarding occurred, banks have eroded, collapsed, and eroded further for distances of up to 8 m in the current winter and the one before. The effect of these changes are passed downstream in changes in sediment loading and pool in-filling. Small debris is less stable and does not play the same role in maintaining channel form.

Changes in debris conditions directly or indirectly affect many life stages of both trout and coho salmon.

Stage 1: Egg Deposition

Debris changes may not affect egg deposition directly. Debris distribution does affect the distribution of adult fish along the stream and, hence, indirectly, the location of spawning-site selection.

Stage 2: Egg-to-Fry Survival

The effects of debris volume and stability changes are indirect on this life-history stage. Reduction in bank and channel stability result in increases of bedload movement and sediment loading. This has negative effects on egg-to-fry survival of both coho and chum salmon.

Stage 3: Fry Growth and Survival
First Summer

The effect of reductions in debris volume and stability in the first summer may have been to decrease overall cover, which may have led to increased predation. However, such an effect has not been demonstrated. The existence of large volumes of small debris in Sections V and VI is considered by Toews and Moore (1982) and Scrivener and Andersen (these proceedings) to have increased the summer densities of fish. This advantage has the potential to be lost in the winter, if the small debris is flushed out or piled up during winter freshets, as occurred in a November storm in 1978.

Stage 4: Fry Growth and Survival
First Winter

Reduction in both debris stability and volume has a strong negative effect on fry survival during this stage. The role of debris, which forms a major element of cover, has been dealt with by many workers including Hartman (1965); Bustard and Narver (1975a, b); and Tschaplinski and Hartman (these proceedings). During the winters of 1977-1978 to 1979-1980, very high survival of coho in their first winter was observed. Higher overwinter survival of fry is related, in a large part, to increased size of the fry in autumn. It is believed that increased fry size and generally milder winter conditions have offset the adverse effects of debris destabilization and loss that occurred in Sections V, VI, and VII.

Stage 6: Coho Growth and Survival
Second Summer—Fingerling Stage

The effects of change in debris volume and stability may be important. Fish are associated with pools and cover in the summer, but direct responses to changes in these features have not been determined.

Stage 7: Coho Growth and Survival
Second Winter—Fingerlings

Changes in debris conditions and, hence, cover changes and associated changes in pools as a result of in-filling may account for the general trend of lower overwinter survival in this stage of coho life history. At this time, however, results do not appear consistent. Coho entering their first winter in the stream in the years 1977 to 1980 showed high survivals, while those entering their second winter have shown a trend toward lower overwinter survival over the same time span (Holtby and Hartman, these proceedings). Some speculation about the cause of this is offered later in this paper.

Stage 14: Movement Upstream
to Spawning Areas

Changes in debris condition have had no demonstrated effect on fish at this stage. Piles of debris which appeared to be impervious to adult fish were observed in Section VIII during the winter of 1981-1982. However, debris barriers that affect upstream movement in the anadromous fish zone have rarely been observed in Carnation Creek during the course of the study.

Sedimentation

Peaks of sediment transport and deposition occur with peaks of discharge naturally in many streams. Sediment loading and movement has been dealt with by Tassone (pers. comm.). Some effects of sediment and turbidity on coho behavior have been dealt with by Berg (these proceedings). Sediment pulses reduce the ability of young coho to hold

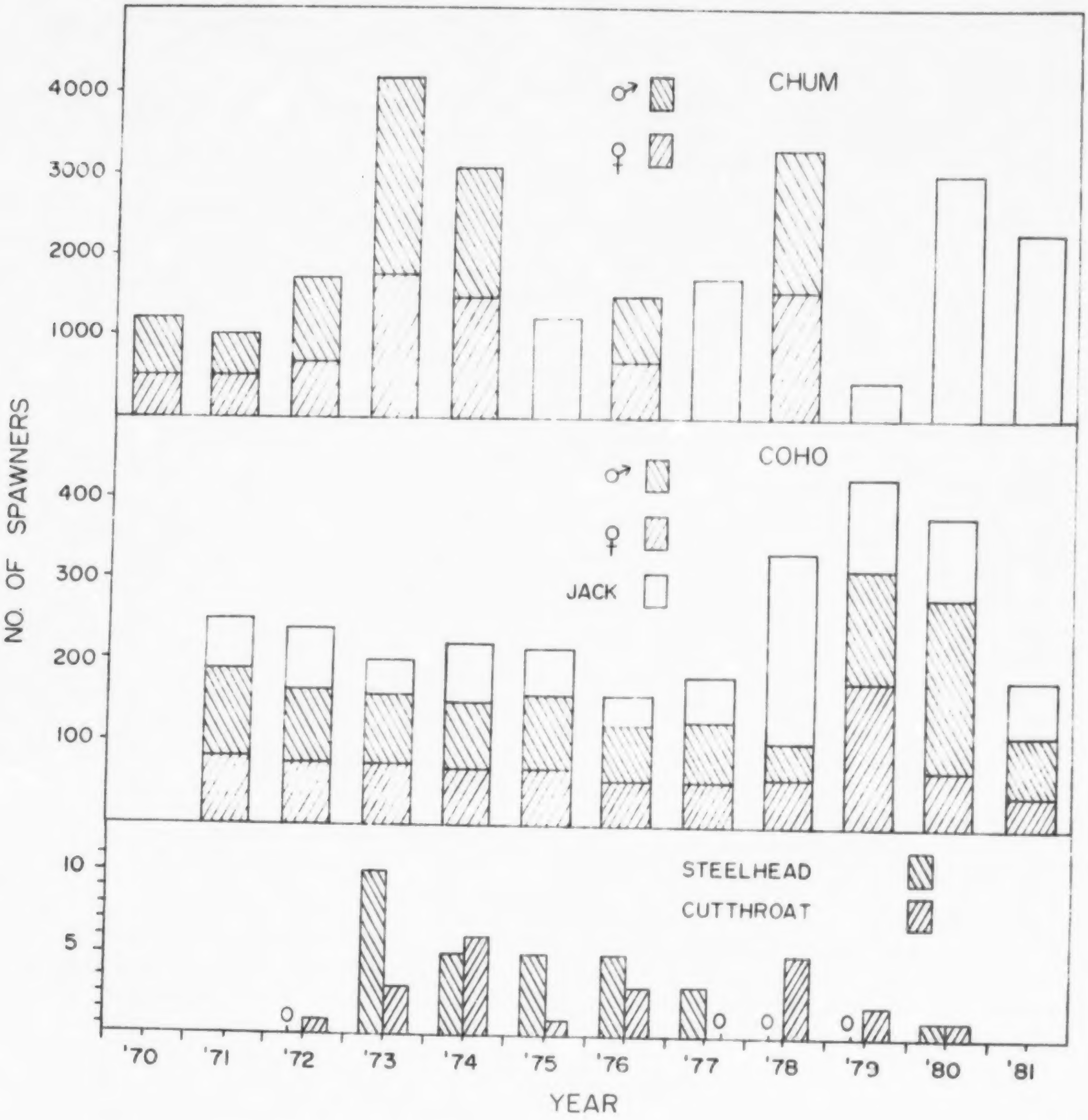

Fig. 3. The numbers of adult chum, coho and trout entering the stream. Most chum salmon do not pass through the fence. Their numbers are estimated and are not precise. The trap did not operate throughout the period of trout migration during most years. Trout numbers are therefore minimal.

territories; they also reduce their feeding efficiency. Sediment also affects egg-to-fry survival. Scrivener and Brownlee (1981) have demonstrated an increase in the deposition of sand in the lower 2 km of the stream. The increase has occurred in the upper third of the gravel layer sampled.

As in the case of other environmental-condition changes, the effects of increases in sedimentation are more significant at some stages than at others.

Stage 2: Egg-to-Fry Survival

The major impact of changes in sedimentation and association changes in gravel quality occurs at this stage for both chum and coho. Egg-to-fry survival for those fish which spawn above the fence (Scrivener and Brownlee 1981) has declined over the past four winter seasons for coho and all but the last season for chum.

Stage 4: Fry Growth and Survival
First Winter

Berg (these proceedings) has shown that short-term pulses of fine sediment may cause young coho to become dislocated in the current. Pulses of sediment, in association with discharge peaks in winter, may contribute to the dislocation of fry from cover during winter.

Stage 7: Coho Growth and Survival
Second Winter

Sediment may have the same effect at this stage as in the first winter (see Stage 4).

PATTERNS OF ADULT RETURNS AND YOUNG FISH PRODUCTION

This section of the paper points out some of the most obvious changes in fish-production patterns from 1970 to 1981 and discusses them in relation to changes within the stream.

Figure 3 summarizes the numbers of adult chum, coho, steelhead, and cutthroat trout returning to Carnation Creek. The numbers of adult chum salmon returning fluctuate between 450 and 4200, but do

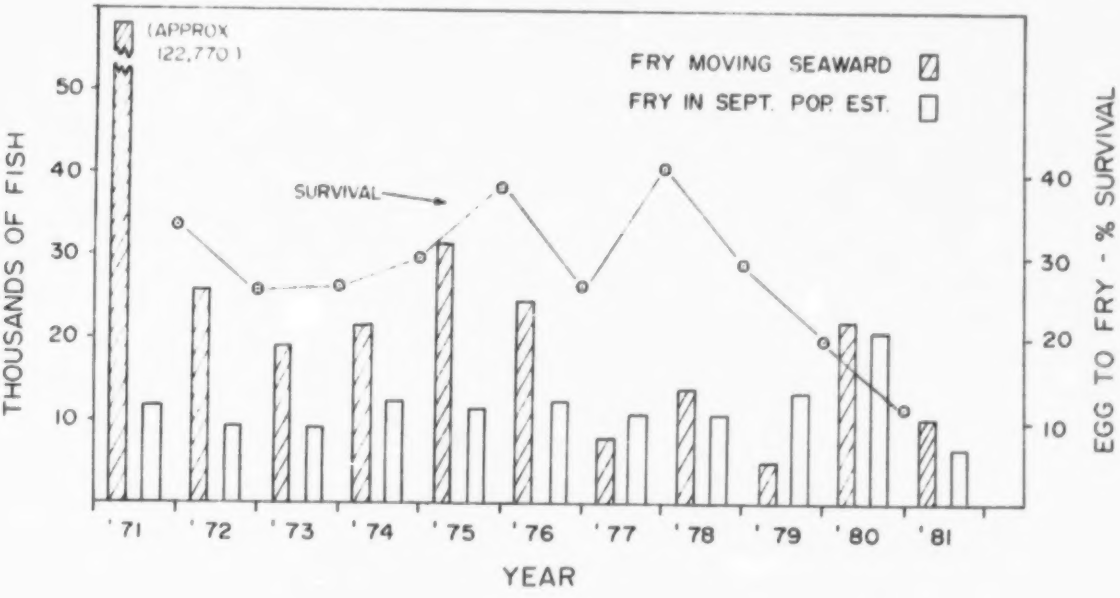

Fig. 4. The egg-to-fry survival rate, the numbers of coho fry moving seaward, and the numbers of fry in the September population estimate, 1971 to 1981.

not show any clear pattern of increase or decrease since 1977 or 1978, the time at which impacts from logging might be expected. The numbers of coho are high between 1978 and 1980 relative to other years. The number of adult coho returning reflects the levels of smolt production (Holtby and Hartman, these proceedings).

The numbers of adult trout sampled have decreased. However, sampling for trout at the counting fence does not extend through their full period of migration. The numbers are not as meaningful as they would be if complete data for the full migration period had been obtained.

The number of coho fry moving seaward was extremely high in 1971 and has never approached that level since. The number moving seaward each year since 1977 has been relatively low, except during 1980. Coho egg-to-fry survival has declined since the winter of 1977-1978 (Fig. 4). The number of coho smolts leaving the system in each of the years 1978 to 1981 was higher than in any of the preceding years (Fig. 5). While the numbers of seaward-moving

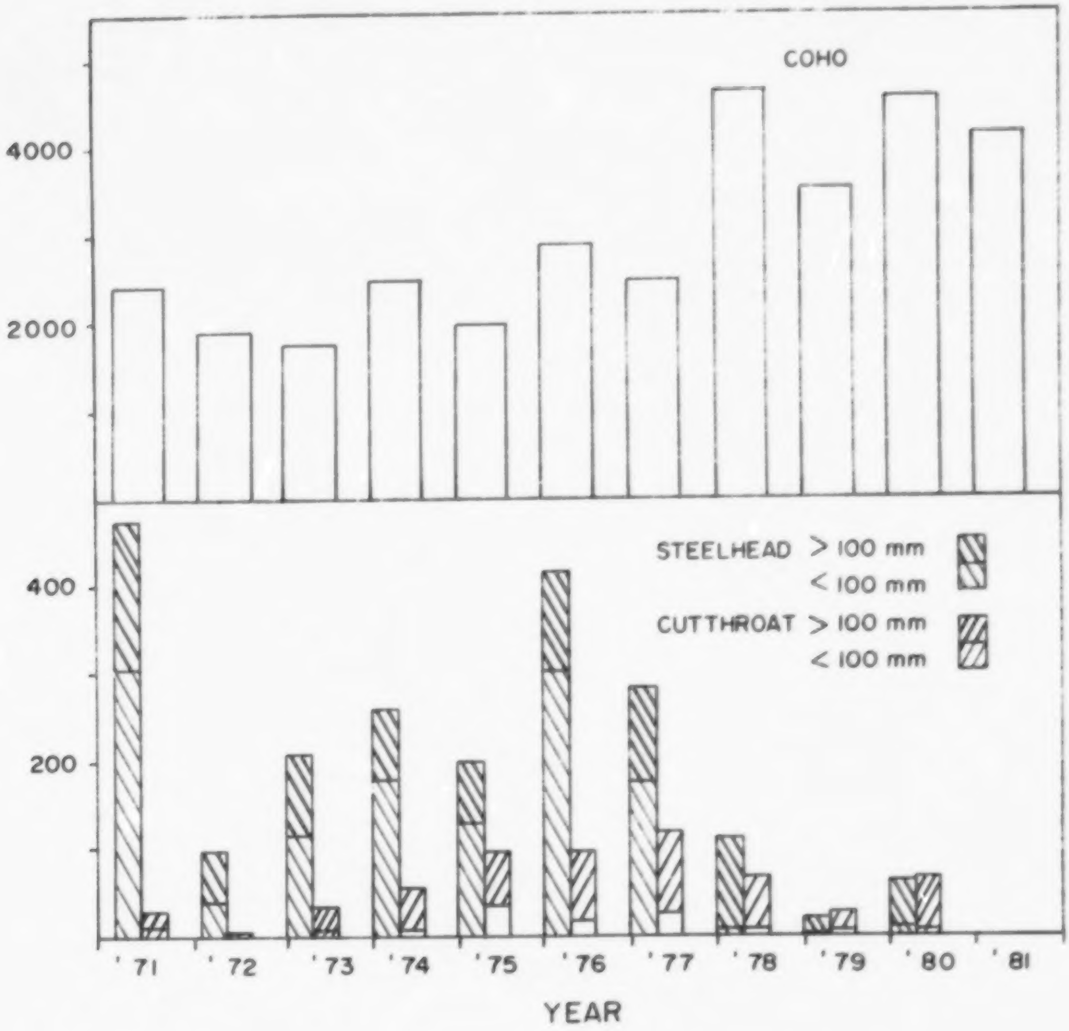

Fig. 5. The numbers of coho, cutthroat, and steelhead smolts moving seaward, 1971 to 1981.

steelhead and cutthroat trout are variable over the total period 1971 to 1980, they appear to have decreased since 1976 onward (Fig. 5). Further evidence of trout population decline is provided by the instream censuses. The total number of trout, estimated during the September population censuses, varied between 2000 and 5500 between 1971 and 1976 (Fig. 6); they dropped sharply after 1976. In addition to this, the fraction of the summer-resident trout population that is made up of cutthroat has increased (Fig. 6). At this stage of the study, we do not understand the mechanisms underlying the trout-population changes.

A number of the major processes that affect coho numbers at all stages from egg to smolt and that lie behind the changes in abundance from 1971 to 1980 are better understood.

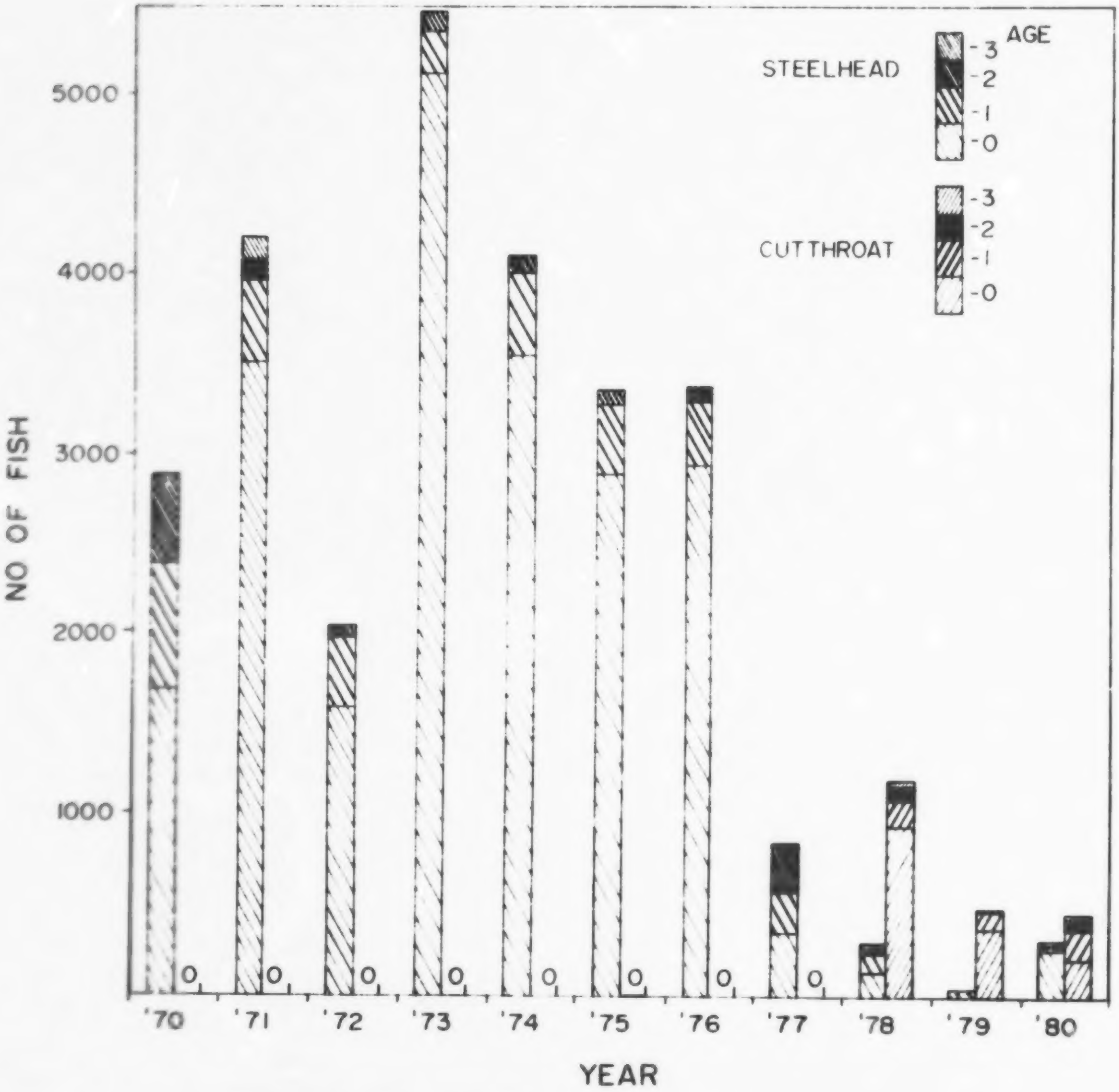

Fig. 6. The numbers and age composition of cutthroat and steelhead trout in the lower 3070 m of the stream in the September population estimate.

The first major changes that have occurred since the winter of 1976-1977 are the decline in egg-to-fry survival and the reduction in numbers of early migrant fry (Fig. 4). The evidence strongly indicates that these changes are related to a decline in spawning gravel quality and increased bedload movement. The changes in spawning gravel quality in the lower 2 km of stream are caused in large measure by bank erosion and slumping in the area in which the trees were felled across the stream and in which some were yarded across it. The breakup of large stable debris and the breakdown of the root structure in the streambanks contributed to the erosion process. Streamside treatment and logging methods are critical with regard to this first life stage of young coho and, as well, of young chum salmon.

Since the winter of 1976-1977, the general climate that influences the Carnation Creek system has been milder. Figure 7 indicates that the number of one-hour periods in which discharge at B-weir exceeded 5.66 and 11.33 m^3/s was generally higher before the winter of 1976-1977. The year-to-year conditions varied widely before the winter of 1976-1977. The number of one-hour periods of flow at 22.65 m^3/s was not lower during and after the winter of 1976-1977. Figure 8 shows the number of one-hour periods when discharge change was great enough to produce a total change of 5.66, 11.33, and 22.65 m^3/s, had such an increase in flow rate persisted for 48 hours. The figure shows another aspect of winter-storm severity by depicting winter discharge variability. Discharge rates tended to change more rapidly prior to 1976-1977 in 3 out of 5 winters. The number of hours of rapid discharge change (i.e., 22.65 m^3/s over 48 hours) was not lower after 1976-1977. Total discharge for the winters of 1976-1977 to 1979-1980 in 3 out of 4 years was lower than all previous years

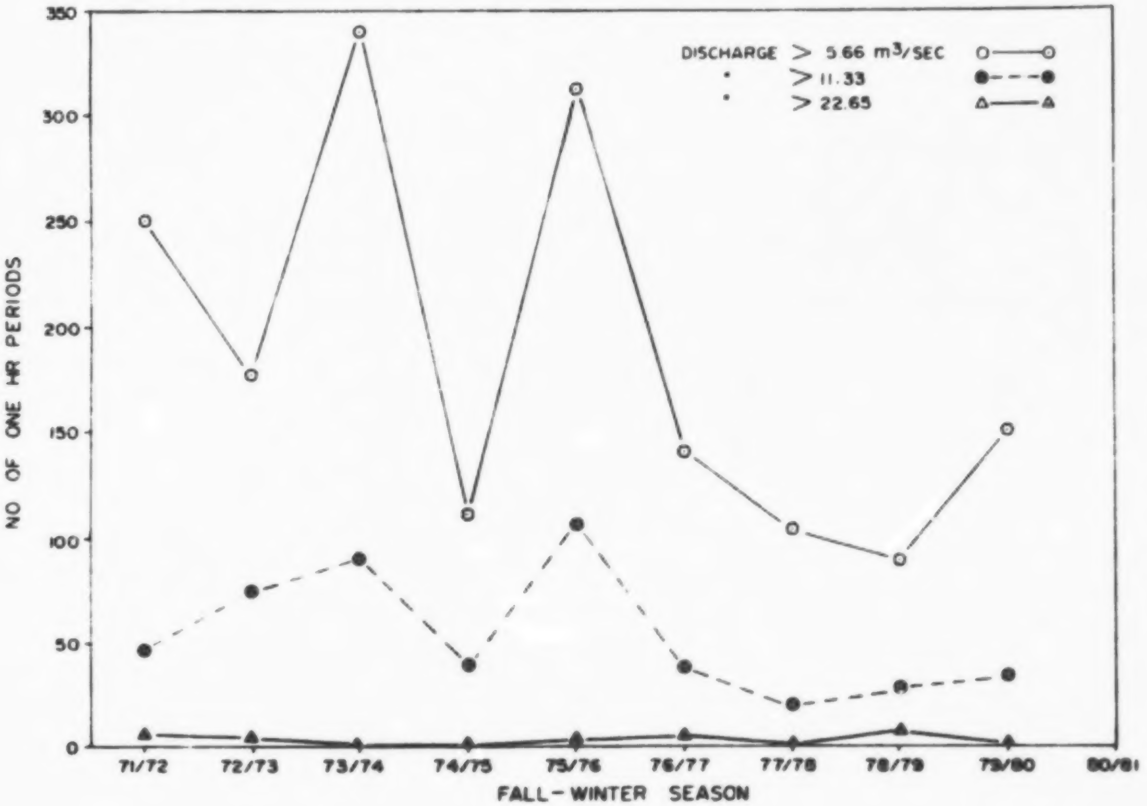

Fig. 7. The total number of one-hour periods when discharge exceeded 5.66, 11.33, and 22.65 m^3/s, September to March inclusive, 1971-1972 to 1979-1980, at Carnation Creek.

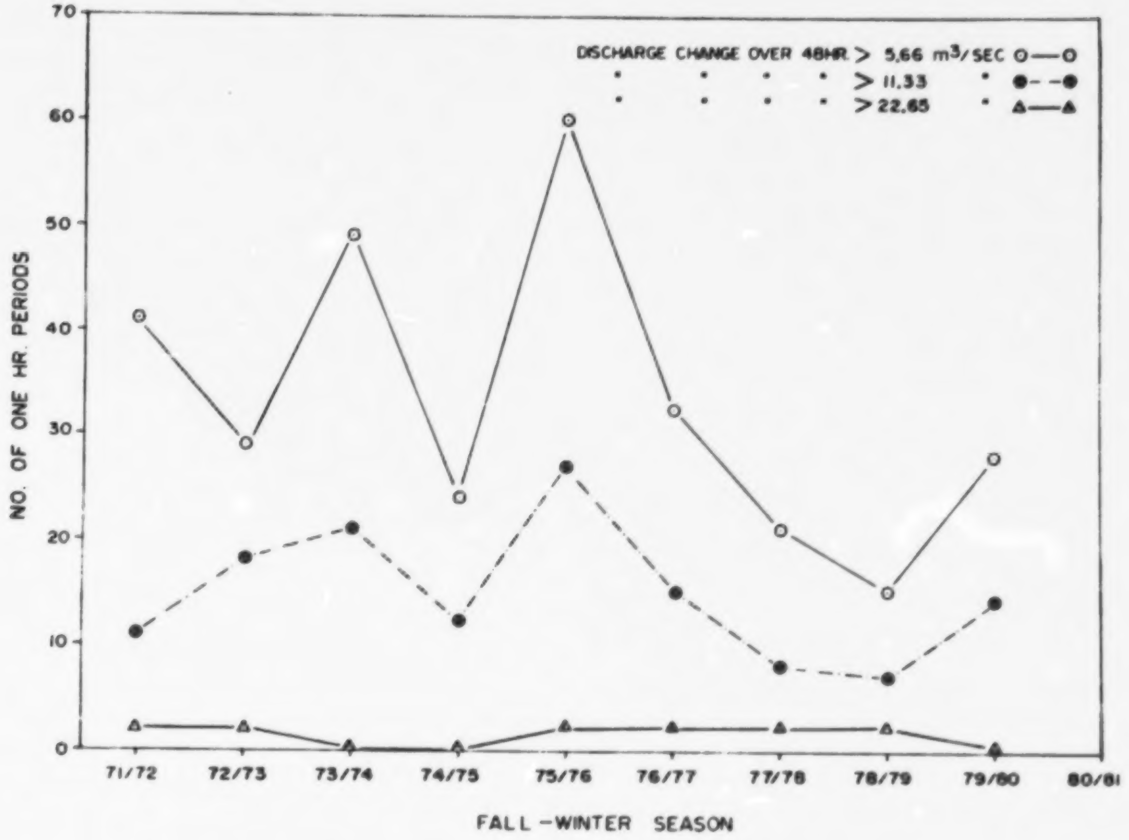

Fig. 8. The number of one-hour periods during which stream-discharge change was rapid enough to cause a change of 5.66, 11.33, and 22.65 m^3/s within 48 hours, if the rate of change persisted for 48 hours.

(Fig. 9). Figures 7, 8, and 9 may not provide a complete method of assessing freshet severity and discharge impacts. Also, the range of conditions during and after the winter of 1976-1977 is not totally different than before; however, the three figures, when considered together, indicate generally a less severe hydrological condition from 1976-1977 onward. The air temperatures have been higher in the Carnation Creek area. The creek temperatures have shown a corresponding increase during winter. Clearcutting contributed, in part, to higher winter stream temperatures (Holtby and Newcombe, these proceedings; Hartman et al. 1982). The net effect of year-by-year weather change and clearcutting has been to produce conditions in the stream that appear to be more benign.

A major result of warmer stream temperatures has been much earlier emergence of coho fry. There are advantages and disadvantages of such a change for coho fry. The early emergence allows the fish to begin spring and summer feeding and growth earlier. This allows them to enter their first winter as larger fish, which is an advantage.

However, shortly after emergence, many coho fry drift downstream. Among fry emerging late in the winter or in the early spring, this response occurs with freshets and does not reflect immediate competitive pressure from siblings. In Carnation Creek, the winter storms and freshets persist until late March and early April (Hartman et al. 1982). The fish emerging early (i.e., March 1 to 30) as a result of

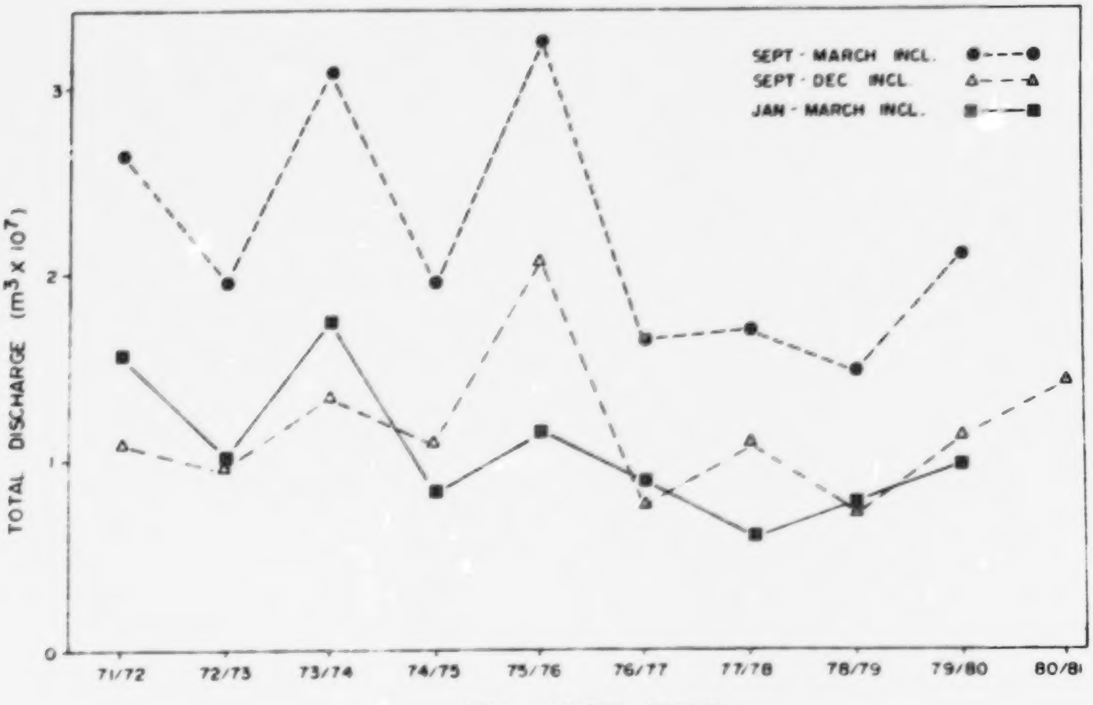

Fig. 9. Total discharge from Carnation Creek, September to March inclusive, during the fall and winter periods from 1971-1972 to 1979-1980.

accelerated development are at risk of being carried out of the creek. Although some rear in the estuary (Tschaplinski, these proceedings), very few are known to work their way back upstream. The post-logging coho fry that remained in the stream generally grew more rapidly than did the prelogging fry.

Forest canopy removal (which results in stronger illumination and higher temperatures) and nutrient addition (which occurs as a result of clearcutting and logging treatment) operate in the stream to push it toward higher production. This is considered to play a positive role with regard to fry growth rates. However, the processes do not appear to produce, as marked, a response among fish in the second summer.

Since the clearcutting began in the watershed, the number of coho smolts going to sea has increased distinctly (Fig. 5). The higher smolt production, 1977 to 1981, is largely the result of high survival of coho from the 0+ to 1+ stage, at which many migrate as smolts. A review of fish-stream conditions and fish-population conditions suggests that two major factors contribute to this. Winter freshet conditions were less severe and water temperatures were higher during the four winters from 1976-1977 to 1979-1980. The fry of the year entering these milder winters have been larger on the average.

With regard to the age 1+ coho that do not leave as smolts, summer growth, in comparison with that of prelogging fish, is not so rapid. Percent survival in this group during the second winter in the stream has declined during the past 7 years. We have not determined what processes in the watershed may account for this observed decline. However, Bustard and Narver (1975a) demonstrated differences in the distributional responses of 0+ and 1+ coho over a range of falling water temperatures. The behavior and requirements of the two year-classes may be different enough to affect survival rates in a changing environment. Bustard and Narver (1975) demonstrated that age 1+ coho occupied the deepest water at low stream temperatures. Maximum depth of the stream has generally shown a pattern of decrease since the summer of 1977 (Schultz International Ltd. 1981). This general pattern is evident in Sections II to VII, but it does not occur in Section VIII. It is possible that pool-depth changes are altering winter survival rates for 1+ coho. However, this is speculative. An alternative explanation of the apparent decline in overwinter survival to the 2+ smolt stage is that recently more of these fish have moved seaward during winter rather than during the following spring.

This brief statement about the biology of young coho salmon has been presented to help illustrate that changes in environmental regimes or conditions are positive in their effects at one stage but may be negative at another stage. The general biology has been presented to illustrate that different conditions or regimes interact in their effect on fish.

Although the information presented here is very general and in many regards incomplete, this paper and the foregoing papers confirm some concerns of some fishery protection workers. They also indicate that all effects of forest harvest are not destructive. The objective of forest-fisheries planning should obviously be to minimize adverse effects and capitalize on those that are not.

MANAGEMENT AND PLANNING: SPECIFIC CONSIDERATIONS

In this section, a number of suggestions are offered regarding planning, management, and enhancement. It is desirable that this type of thinking be expanded during the rest of the project and that the ideas be considered by managers. However, just as the system is very difficult to predict completely, it will be difficult to predict or determine successful management strategies in every case. The complexity and variability of the system and of our results suggest that some failures may occur in the best intended plans. To use the kind of data that come from systems like Carnation Creek, forestry and fishery managers will have to take chances, fail occasionally, and still be prepared to try again. Having a good understanding of much of the ecology of the system should help managers to understand this.

Streamside Vegetation Management

Although analysis is still at an early stage, the project has identified important aspects of streamside-vegetation management. It is clear that the overall streamside-management process determines the volume, stability, and future generation of large organic debris. Debris and live roots assist to maintain bank integrity and, as such, are of direct importance in controlling one source of sediment. The condition and composition of the leave strip will determine the nature of terrestrial-insect input and leaf-litter input. It will, in part, control primary production in the stream.

If it is possible to do so, leave strips should be left. From this work, it is evident that this need not be a dense shade-producing stand. Simple alternating cut and leave blocks along a stream may not be a satisfactory protection measure. In Section III where trees have been cut to the bank for a short distance of about 40 m, the stream has eroded the bank a distance of up to 4 m. This has occurred quite rapidly.

Regarding streamside leave strips, there is cause for concern over rapid blowdown. However, if the trees that are left at the streamside blow down over an extended period (depending on direction of fall), many of them would have the potential to form in-stream cover for fish. If streamside trees must be felled, it is clear that they should be jacked away, and yarded away, from the stream. If possible, small trees should be left along the stream as a future source of large debris. If streamside trees must all be cut, it would be desirable to develop methods that might create new streamside strips that grow more slowly or are out of phase with stands further back from the stream. Streamside alder should be left to maintain live-root systems to help stabilize the banks. Regenerating alder rapidly begin to restabilize gravel bars and banks and, hence, the stream channel. This phenomenon is particularly evident in parts of Sections V, VI, and VII.

At this stage, our work suggests that vegetation for shade (i.e., maintaining low stream temperatures) may not be a critical consideration. However, the large openings SC 700-17 and SC 700-18 are new. There is no certainty that temperature regimes which have risen will stabilize immediately.

Protection of Small Tributaries and Side Channels

It is clear that these play a critical role in the production of trout and coho in systems such as Carnation

Creek. They serve as rearing areas in the summer and as refuge areas in the winter. With any loss of main-stem cover, the side channels become more important. Even if these tributaries are intermittent, as is 750 Tributary, fish may move into them on rising winter freshets and out of them as the storms abate.

In the preparation of cutting plans, all small tributaries should be located. If possible, operation of machines within them and yarding across them should be avoided. They should not be blocked by roads. The winter flow conditions in small tributaries should be determined before forest harvest planning. Tributary 1600 is very small, perhaps 350 m long. It provides critical winter habitat, as well as rearing summer habitat, for young salmonids. However, before logging, it supported not only young fish but also small numbers of spawners.

Estuary Management

The work that has been done by Tschaplinski (these proceedings) has demonstrated the extreme importance of even short stretches of estuary. Some 700 to 800 smolt-sized fish may originate in about 200 m of estuary and side pools. The integrity of stream channels, banks, side pools, vegetation, and estuarine groundwater supply should be maintained. If construction or other activities are carried out in the estuary zone, they should be carried out on only one side or the other and away from the stream if possible. Location of activities should be planned to minimize effects on channels, side pools, vegetation, and fresh-salt water dynamics.

Slope Stability

There are some types of problems which occur in forest harvest operations in other areas that do not have a high profile in Carnation Creek to date. Three slides of mud and debris occurred during a wet period in January 1982. Although such events are not frequent in Carnation Creek, the phenomenon is mentioned here because the valley form and structure gives some indication of soil and slope situations that are less sensitive. It is believed that little mass wasting has occurred because the valleyside soils are shallow and porous. They are drained rapidly, in part, through macrochannels (Hetherington, these proceedings). The valleyside slopes are irregular with many rock humps and ridges. They are not extremely high. Cutblocks SC 700-17 and SC 700-18 are higher, more uniform slopes. They have been clearcut in the last 2 years. It is too early to judge their response.

Road Construction and Sediment Release

In this watershed, much of the road network has been constructed in shallow soil and solid rock. Furthermore, sediment sources are not partitioned among road construction, road use, yarding effects, mass wasting, and bank erosion. In the watershed immediately east of Carnation Creek, major erosion has occurred in one short, steep section of road (703?) which was built in a deep gravel, sand, and clay substrate. It is evident that construction in such sites should be avoided if possible, particularly if they are located immediately above a stream.

STREAM IMPROVEMENT AND FISH POPULATION MANIPULATION

Beyond the situation of managing in such a way as to minimize damage or to take advantage of positive effects of forest harvest lie the important opportunities of small-stream improvement. Stream-improvement programs in British Columbia are well established. The suggestions offered in this section of the paper may be more a matter of confirmation of existing ideas than offers of new ones.

Streams With No Large Organic Debris

There are many streams in coastal British Columbia that, because of past forest harvest or the state of forest development, have little stable in-stream cover in the form of debris. A program of mapping stream sections that are adjacent to access and to sources of material for stable cover would be a valuable first step. A second stage of such a program would involve placing stable debris and monitoring its behavior and its use by fish.

In-stream debris, placed as cover for coho, must be located in such a way that winter velocities within it and downstream of it are low. The cover must be three-dimensional, so that fish may remain within the spatial interstices in it, as they do in submerged root masses. We believe that the water space dimensions within cover can be quite small, i.e., 10 cm to 15 cm. Ideal cover might consist of a complex of large debris (cabled or keyed in so that it is stable) with smaller debris or root wads attached alongside, or downstream, of it so that strong currents do not pass through. Root wads tied in place at the side of a stable pool would serve as good cover. We would suggest that, if cover is placed experimentally in a stream the size of Carnation Creek, the volume of a single-cover complex should be in excess of 3 m^3. However, more work on the nature of an ideal cover complex is needed.

At present, many local stream-improvement projects involve stream clearance. Participants in such projects should be absolutely certain that the woody debris they clear is an obstruction, not just good winter cover, as is the case with much large stable debris.

Streams With Heavy Canopy

The analysis of results to date is inadequate to allow us to quantify net effects of primary production enhancement by canopy removal versus changes in leaf-litter (detritus) input. However, the possible benefits from thinning any heavy canopy over small tributaries should be considered. We have seen that clearcutting can produce positive effects on coho through summer stream-temperature regime changes. Any removal of streamside vegetation to enhance light and temperature conditions must be done in such a way that the negative processes of bank destabilization and erosion do not occur.

This study is providing a further predictive capability of stream-temperature change in relation to area clearcut. It is most desirable to improve this understanding so that it can be applied as a positive management tool in other stream systems. In order to make the best use of the capability to manipulate thermal regimes, it will be necessary to understand more about the effects of clearcutting in areas of different aspect (i.e., south-facing versus north-facing). It will also be necessary to be able to weigh the benefits of summer-temperature changes against negative effects of early emergence, the result of stream-temperature increases in winter. This will be studied in future phases of the project.

Side-Channel Expansion

Many streams are joined by small side channels or are complexed into slough systems. This is particularly true of streams like Carnation Creek which run through reasonably level valley floors in their lower reaches. In a program of mapping streams for access and debris-placement potential, sloughs and side channels should also be mapped. Depending on their depth and condition, these side channels and sloughs could be expanded and deepened to assure the maintenance of water. Stable cover could be placed in them. Since the movement into side channels is largely coincident with the period of dislocation from areas of inadequate main-stem cover, side-channel enhancement may be an alternative where the size or condition of the main-stem precludes improvement. In stream systems in which the main stems are difficult to work because of size, discharge extremes, or other conditions, the best opportunities for enhancement may lie in the small side channels or adjacent ponds.

Intertidal Habitat Improvement

The use of small pools in the intertidal zones of the stream by substantial numbers of young coho (Tschaplinski, these proceedings) suggests that there are major opportunities for creation of extra rearing space in this zone. This concept has been discussed and proposed in the past (Mason, pers. comm.).

Relocation of Seaward Moving Coho Fry

It is considered that the majority of the fry which leave the stream early in their first summer are lost or, at best, suffer a very high mortality. When replaced in unoccupied habitat, these fish can survive and grow well (Mason 1969).

In streams such as Carnation Creek, we can predict the conditions under which such fry will move and, hence, could be captured by trap. The locations of small, unoccupied coastal ponds and lakes (particularly those with access and those near to salmon or trout streams) should be catalogued. Local projects could involve annually capturing and relocating a portion of the seaward-moving fry.

Many of the suggestions made would involve the use of heavy equipment and people skilled in its operation. There would be costs and it is certain that there would be discussion of such costs. Technically, small-stream improvement is not extremely difficult. It is desirable to explore ways of implementing small-stream improvement more often and involving the forest management sector. Perhaps preparing for road construction, logging, postlogging treatments, new tree planting, side-channel improvement, large-debris maintenance, intertidal-pool construction, etc., might all be planned by small interagency teams functioning with broader planning perspectives than we presently have.

This type of approach would involve the need for an intensive inventory of each system as a prerequisite to forest harvest planning. On the basis of work done in this project, it is possible to outline such an inventory with both forestry and fisheries interests in view. It would include, but not be limited to, the following types of information:

- Forest stand information: species, volumes, location, and elevation.
- Relevant details on access location.
- Slope characteristics and stream-valley shape.
- Soil characteristics.
- Stream-channel structure.
- Large organic debris in stream—prelogging.
- Description of prelogging streamside vegetation.
- Size and species composition of all streamside trees.
- Fisheries inventory for species composition, population sizes, and distribution along the stream.
- Location of barriers to fish movement.
- Detailed location of small side channels and sloughs.
- General flow patterns of small side channels.
- Distance and access to small unstocked lakes and ponds.
- Map of the estuary.
- General features of structure and flow patterns of stream channels and side channels in the estuary.
- Determination of the amount and type of community interest in watershed projects.

This section of the paper and the planning ideas involved are, in part, a "reinvention of the wheel". The counterpart for this approach has been developed in the Coordinated Land Use Plans of forest and range units of the Kootenays. In conclusion, watershed management for logging and fisheries requires that we establish interdisciplinary groups to do the following:

- Develop a detailed picture of the watershed to be logged, including the kinds of features listed earlier in this section of the paper.

- Employ, as much as possible, knowledge of watershed processes such as those being brought out of the Carnation Creek study and other research.

- Develop a long-term plan for the watershed including postlogging treatment, reforestation, reestablishment of in-stream cover when required, relocation of surplus coho fry if early-spring flushout occurs, and habitat improvement in side channels and the estuary as might be feasible. The managers must be able to continue to interact and to work with the watershed and its resources long after the logging trucks are gone.

The management approach indicated here is obviously very demanding in terms of people's time and money. However, if society wishes to have fisheries and forests managed for optimum benefits in the long term, new perceptions regarding support, agency involvement, and policy will be required.

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QUESTIONS TO G.F. HARTMAN AND L.B. HOLTBY

Question *(Unidentified)*: We've heard a lot about winter habitat being a critical element in the survival of the juvenile coho. And yet we've looked at the Carnation Creek data that you've presented showing that the smolt production has increased following logging. Now I see dichotomy there between where habitat is being important, very critical to survival. I heard of habitat loss, and yet there is increased smolt production following logging. Can you explain what is happening there? There is increased production of smolts and yet their habitat apparently is being lost in Carnation Creek. I would assume habitat change would lead to a reduction in banks, pool volume, and maybe debris and in fish.

Answer *(G. Hartman)*: I think there were some other things happening. During the four winters when we had that substantial production of coho smolts, we also had winters that were really mild compared to the prelogging conditions. We looked at three or four different ways of expressing winter severity in terms of hydrological regimes. We can't look simply at the before-and-during-logging situation alone. It's necessary to consider hydrological conditions. I would expect that, when we look at the last two winters we've had, we may see lower smolt production.

Question *(Unidentified)*: Well, has there been any change though in your estimates of winter habitat from prior to logging to after logging? I am asking about change in regard to pool volume, undercut banks, debris?

Answer *(G. Hartman)*: As Dave Toews pointed out, in the sections getting the intensive treatment, the volume, the size of the debris pieces, the stability has gone down. In addition to that, there are a number of other changes that have taken place in those sections of stream. The stream has tended to straighten out. There has been substantial erosion of banks in the intensive treatment areas. I am referring to data that we haven't presented here as such. However, it was summarized in a report by a consulting group. They demonstrated that the cross-sectional area of stream in the intensive-treatment areas had decreased. They also demonstrated in the data summary that the maximum depths in some sections had decreased.

Comment *(D. Toews)*: I don't have the maximum depth data at my fingertips. I believe there was a slight decrease in the cross-sectional areas in at least two of the three study sections.

Question *(M. Waldichuk)*: Gordon, in a paper on seaward movement of coho fry, you showed some striking relationships of your downstream migration of fry with your hydrographs in the stream, but they always preceded the peaks. What was the stimulus for the fish to begin to move downstream?

Answer *(G. Hartman)*: I don't know. I'm wondering if it's a straight case of the rainfall starting them moving or, if, in fact, there's some sort of rainfall and temperature signal that is involved?

Comment *(C. Scrivener)*: We talked about another thing, too, what the peak in many of those storm events at 400 cubic feet per second or so with water out in the bush. You're talking about the start of the storm, you may have something like around 32 cubic feet in all the stream than before. It won't be full to the height of the bank, but it will be full over the bottom of the streambed, and there's certainly velocities here at 32 cubic feet per second. Nothing like the velocities at 400, but there are velocities at that point. We've noticed on fish movement, when we're operating the fish-counting fence, or I should say that Bruce has noticed, that at the fish-counting fence you get a number of fish moving, including sculpins and smolts, leaving the system at the start of the storm, and when the storm reaches nearly 200 cubic feet per second, there are no more fish moving. It seems to be that they've either found a place to hide at that point or else they're gone.

Question *(P. Tschaplinski)*: Gordon, you showed a graph where the mean size of Carnation Creek migrant fry was essentially the same as the mean size of fry that remained in the stream. If you are given that fry of relatively the same size would compete most strongly for resources of space and food because their spacial requirements and food requirements would be more likely be similar than among fry of different sizes, would you not then consider that competition perhaps does have a role to play in the movements?

Answer *(G. Hartman)*: It may, and I didn't suggest that social interaction doesn't underlay some of the movement. What I have pointed out is that you don't have much disparity between the size of the migrants and the nonmigrants. That is described in some of the other work that has been done. I stress this because I think there may be something that involves one mechanism causing movement early in the year and another mechanism (social interaction) playing a more important role later in the summer.

Question *(P. Tschaplinski)*: There is a difference here because in the other work that has been done, competition in coho has frequently been seen as a process in which larger fish are somehow more fit and displace smaller fish from the stream. But your data shows that the case of Carnation Creek might be different in that the displaced fish are essentially the same size as those that remain in the stream. So the earlier concepts of size and competition perhaps do not hold in a natural stream.

Answer *(G. Hartman)*: I think that they're masked by other things in this system. That's the interpretation at this point.

Comment *(Unidentified)*: Yes, just to comment about your remarks on leave strips, although there aren't any proper leave strips in this stream, there are areas that still have stands of conifers and deciduous right up to the bank and I wouldn't want the impression left that that wasn't the case because that's significant both in the input of organic material and stabilizing banks.

Answer *(C. Scrivener)*: Yes, okay, all I was trying to say is that we shouldn't confuse what we're referring to as leave strips in this project, and what a lot of management people might refer to as a leave strip of merchantable timber of so many chains or metres from the stream margin. There's nothing like that. They're allowed to take everything, all the conifers, up to the stream margin. They take what they can fell away from the stream. But certainly, the deciduous vegetation is left intact.

Question *(unidentified)*: I haven't heard any specific mention today in regard to the study on bank stability, the impact from harvesting both immediate and with time, and its contribution to sedimentation, or conversely to the addition of cover, such as root wads.

Answer *(C. Scrivener)*: First of all, there is a series of detailed maps that have been made on each of these study sections since 1971. We are just now in the process of sitting down (or I should say, Dave Toews is) and processing the maps to measure changes in the actual morphology of the banks. As far as sediment is concerned, we've noticed simply that much bank has been removed in certain locations by the November 1978 flood and subsequent storms. There has been 6 or 7 feet of bank removed in some locations. These eroding banks appear to be the major areas where the coarse and the medium sands that are ending up in the gravel are coming from. Dave Toews has observed a lot of sediment movement in relation to road building. But this involves mainly the fine-sand category. We haven't noticed increases or changes in the quantities of these in the substrate itself.

Question *(Unidentified)*: How could forestry management help you resolve some of the problems that these studies have identified. Another symposium with forestry participation? Is intensive logging going to continue or are new technologies or more selective technologies going to emerge?

Answer *(G. Hartman)*: I wouldn't want to prejudge all of the studies, but I think that some of the things that are coming out of this study indicate that, when you remove trees, there are some effects that would appear to be positive, and there are other things that appear to be negative. I think the whole name of the game of the management process is to make the most of the positive things, to reduce as much as possible the negative effects of the timber harvest, and to try to get the best condition within the watershed after it's finished. I think that this work points the way for that kind of thing. It probably tells us that it may be desirable to clear pretty well up to the edge of sections of a stream, if this can be done without causing bank collapse. I'm talking very generally; it may certainly be desirable to leave the large, stable debris in there. The forest managers may well become participants in the stream-improvement process. If there isn't a lot of debris—large, stable debris—in the system before they go in, you may well go over the system with them and they will put some in there and leave it. I can't see why that kind of thing can't be done. Perhaps after the operation is over, they may indeed want to go back and clear some of the bank vegetation. I think that, in any of the things that happen, the thing to keep in mind is that each thing you do may have a number of different kinds of effects, and that what you want to look for is the best balance among all of these. It's going to vary in different watersheds. The ability to go ahead and manage these systems on the basis of some sort of special prescription that incorporates what we know with good field ecological judgement is very important. It will require that you have people who've got flexibility and have good information on hand. It might also mean that the companies that are doing this must be prepared to manipulate a little bit. I think this should help to point the way to better prescriptions. People are talking about a lot of these things already now. It is important that we provide information that helps them. I think many resource managers today are quite positive about this type of approach.

Question *(J. Louie)*: Down the road, with all the information you've collected from these projects, do you envision that you'll ever come up with a recommended set of management guidelines for watershed management with respect to size of openings, grade of the cut, percentage of cut of a watershed, and recovery period?

Answer *(G. Hartman)*: I would hope that what we could do is help people to fine-tune the ones that they've got.

Comment *(C. Scrivener)*: And realize that you can't apply a single management pattern to all watersheds, that you've got to have a lot of flexibility. And again, this requires a good, sound, ecological management approach to individual watersheds based on the processes one is likely to observe in those kinds of systems.

SUMMARY COMMENTS ON THE BACKGROUND PAPERS

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It is an honor for me to be asked to come and speak to this conference. I'm speaking not only for myself but also for my colleagues in the State of Washington. We have been watching, with interest, your study of the effects of logging on fisheries resources here on Vancouver Island. We are interested in your findings and how they can be applied to our land management in the State of Washington. We hope to use some of the work that you have done to help us understand the physical and biological stream processes that are brought about through timber and fisheries management. I stress that it is the processes that are important, if we expect to apply your findings to other situations.

I would like to congratulate Dr. Gordon Hartman for a very professional and well-organized conference. The papers have been extremely well presented and their points have come across well. Briefly, I will attempt to highlight some areas of study that need further development.

I hope that, as the Carnation Creek study procedes, serious effort is directed toward explaining some of the coho salmon population time-series data that is being collected. Also, I feel that the organic-debris response to logging along the stream and the resultant stream-channel instability have been the most important parts of the findings. These organic debris responses have major implications in timber management along stream courses. As Al Edie and others have emphasized in their presentations, it is the physical dynamics of streams that are so important to fisheries resources.

I had the opportunity to visit Carnation Creek back in the early 1970s. Drs. Dave Narver and Tom Chamberlain were gracious enough to take me and some of my students from the Clearwater River study out to look at Carnation Creek before it was logged. We were especially impressed with the walkways through the forest, the salmon and sculpin weirs, the camp, and the whole layout. I was very envious of the whole setup. I still am today.

The State of Washington Department of Natural Resources is presently involved in rewriting their whole forestland management program, with some emphasis on upland and streamside management for nontimber resources. I will assure you that some of the findings of this study will be incorporated into our work, as have been a lot of the studies conducted in Oregon and Alaska. Extensive logging and land-management studies and the effects on the aquatic systems are data-building processes. On the Clearwater study, we have built our work, in part, on previous investigations, just as researchers before us built on the studies before them. I am sure the Carnation Creek study did the same—indeed, that has become obvious to me. It has been a complete study and is giving the kind of time-series data that is so needed to explain some questions in fishery biology. I would like to mention that some of the earlier studies at Carnation Creek, that of Bustard and Narver for example, were particularly helpful to us on the Clearwater River. We have put a lot of emphasis on the winter season and its effects on fish. It is my opinion and the opinion of many others that Bustard and Narver's work was a quantum leap for freshwater salmonid biology. Prior to this study, winter ecology of coho and steelhead was discussed a lot, but we hadn't done much about it; and I feel they should be acknowledged for doing something about it.

During the mid-1970s, we (in Washington) didn't hear much from the Carnation Creek studies and we wondered what was going on up here. We were finally glad to hear from Charlie Scrivener and Mike Brownlee when they gave a talk to our salmon-spawning gravel conference in Seattle a couple of years ago. It was the first time we had heard of Carnation Creek data for several years and we appreciated that.

I would like to say now that the work that Dave Toews and Keith Moore recently published on large organic debris is quite significant. Unstable debris in channels has vital consequences for fish populations. These consequences affect stream-channel structure, both physically and biologically. Both these consequences and some we probably haven't thought of have major meaning for fish populations. The biological community and processes are literally at the mercy of the physical environment. As stream channels become less stable, fish populations and their biological processes can only be interrupted. This interruption is of particular concern to winter survival, which I think on the coast is something to be concerned about. Increased water temperatures in the summertime may increase fish growth, but the fish still must survive through the winter. I think we can all agree that smolts are the bottom line in anadromous salmonid freshwater production. Generally, your data appear to be extremely good. And all the studies—from Culp's work on detritus to Bustard and Narver's work on winter ecology of salmonids to Eugene Hetherington's hydrology work and the sediment work and all the other studies—no matter how insignificant they may seem now to a fisheries biologist, are important in understanding the watershed processes. They allow you to cover all the bases when you discuss what is going on in the stream environment as a result of upslope land-management activities.

In the next few years, I would suggest that more attention be given to looking at your time-series data and carrying out some particular experiments that will explain some of the trends you have seen in this data. Do not go along continually collecting time-series data without testing some hypotheses. I think it is important now that fisheries biologists and scientists be carrying out these experiments. These people are the people who are going to have to explain what is going on. Therefore, I would like to emphasize again that we need experiments now to explain some of the changes in the time-series data. We need some hypothesis testing now.

One example would be cold branding individual fish from some of the populations in the various logging-treatment areas and looking at, during the summertime and subsequent winter, the apparent redistribution of these fish to areas outside the treatment areas. You might even study the eventual contribution to smolt production of fish originating from control areas compared to the various logging-treatment areas. You are in the fortunate position where you have the ability to do this kind of study. Perhaps this work will explain some of the increases in coho salmon smolt yield that you are experiencing in the postlogging period.

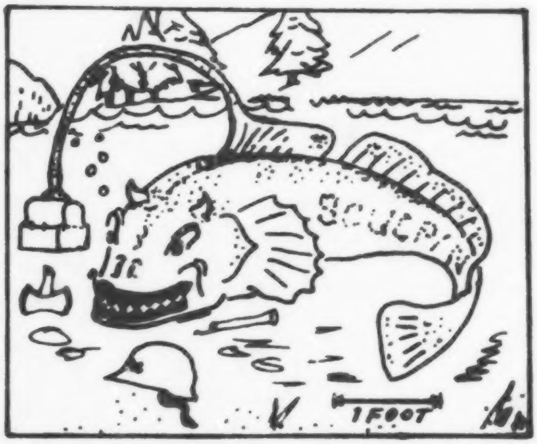
We must seriously address the role of large organic debris and debris budgeting in future forest management. We need to consider not only the short-term but also the long-term replenishment of large organic debris in stream channels. I am talking about big wood, not just branches and leaves, although they are important. I am talking about big wood that provides for the physical structuring of the streambed environment. In this regard, I have a little jingle. I use it in Washington when I speak on this subject; it always gives people a laugh. **Streams will always need big wood—too much too fast is no good.** It has to be a gradual replenishment. In-channel processes are dependent on the streamside area and their dynamic interaction is critical.

You need to continue the education of habitat-protection biologists and foresters on the role of large organic debris. Moderately high water temperatures in some coastal areas may be beneficial and, on the contrary, may be harmful in other areas. This is something that always has to be considered on a site-specific basis. But large organic-debris budgeting is always an important part of streams in forested areas because its physical processes and fish-habitat structuring are very delicately balanced in the watersheds. Large organic debris is vitally important—it may regulate basic multiple species and year-class fish production and, thus, the carrying capacity of streams in forested areas. There has been a considerable amount of research in Oregon on the role of organic debris in streams—I'm sure that many of you are aware of it. I am thinking of people like Jim Sedell, Fred Swanson, Jim Hall, and his colleague Baker. There has also been some good work at Carnation Creek on the importance of stable organic debris, and I think that some hypothesis testing is in order on your stream to build on the work that has gone before. This kind of experimentation might help to explain some of your time-series data on coho-population dynamics. I know that most of you are aware of this, as well. However, I would like to say that it is my understanding that the postlogging results are still preliminary. Some highly dynamic winter flows would now really put the winter ecology of coho salmon to the test. Because of this, I think it is a little preliminary to judge the total impact of logging on this watershed; we need to keep that in mind.

(A question was put to Jeff Cederholm here concerning the size of organic debris needed in streams. His answer was, "Well, it depends on the stream; a large river system may take an old-growth sitka spruce (maybe a number-one peeler) to hold its embankments and streambed together because of the forces involved in a large stream. A small cascading stream may require only a small log. It depends a lot on the stream order as to what size of logs is important in the structuring of that stream."

I think that it is important now to design, with the input of both fisheries biologists and foresters, a streamside-protection-and-treatment approach that recognizes the need for site-specific determinations. The size and shape of streamside corridors should be flexible. However, we should be realistic in terms of what is really needed, based on what we know. Streamside-protection areas should be designed so they have a high likelihood of being effective, and not cause people to loose interest as soon as the first tree blows down. Streamside-protection areas should be designed on a site-specific basis. You should shape these protection zones to fit local landform, climatic, and resource conditions. I suggest that this approach will increase their likelihood of surviving severe wind conditions. What I am suggesting is to go into each streamside-bordering unit and mark individual trees that are not needed by the stream and carefully remove them. You may choose to use cable-assist felling, tree jacking, and directional felling to assure that the stream integrity is protected. I would encourage the foresters to think very seriously about the layout of their logging plans for their road systems, with the idea of logging away from streams rather than across them. When this approach doesn't work, they should consider bringing the trees across through periodic openings in the streamside-protection areas. This will require the extensive use of side-blocking techniques to gather the logs together that are on the other side of the protection zone. There may be some buffer strips that will have to be left entirely in tact, and there may even be entire watersheds that will have to be left unlogged. On the other hand, there may be some areas where leaving a buffer strip is entirely unwarranted. This will depend greatly on your prelogging resource inventory. Above all, perpetuate a mutual respect and good working atmosphere between fisheries biologists and foresters (even with loggers) so you can work out a realistic solution to streamside protection.

Thank you.



Cottus youngii (Ringstad), the leave-strip sculpin.

Comment *(W. Young)*: No doubt now we're going to get some questions. We have a short time now for questions and comments. Before starting it out, I would like to offer a couple of comments. It seems to me that, as a layman or a forester like myself, what is coming through from these studies is that the weak link in the whole thing is the movement of organic debris, and that's what's causing the sedimentation and that's what's causing streambank erosion and so forth. And it seems that's the weak link in the process that we have to address. In following along with what Al Edie said, I find it difficult to accept that to let debris enhance the stream, by accident, will be better than physically placing debris in the right spots. I suggest we use the right type of debris and enhance the stream as part of this whole forest-harvesting process. I think that that has to be one of the ways we have to look at it. If certain types of debris are valuable and are enhancing the stream and others are a detriment, then we have to achieve a reduction in detrimental debris input and we have to then get the beneficial debris into the stream. And surely, man's doing it, rather than letting it happen by accident, seems to me the best way. And I also think, if we talk about who pays, it's a lot of work in resource management; I think that's the last question we consider. If we start out with "who pays", we never accomplish anything. I think we have to start with what's beneficial, what should be done, and look at the broad costs and then, after we find that "yes, it's feasible", it's within the dollar framework, then the last thing we consider, once we know what we want to do, is who pays. I had to get my two ideas in here.

It's open now for questions to any of our panel members.

Comment *(D. Smith)*: I wonder if I could make a couple of comments on some references made to the paper I gave on soil disturbance. In that paper, I talked about a couple of types of disturbance—one was bedrock exposure and the other was mineral soil exposure. And really, mineral-soil exposure was the important one and that was the one I had in the draft of my paper. As for the bedrock exposure, I more or less mentioned this in passing and that was referred to as being 1.5% increasing to 3% bedrock exposure. And I didn't say that bedrock exposure was actually just an aesthetic problem, although it might have come through like that. But the mineral-soil exposure, as I think you could see from the graph, was important and much more than an aesthetic problem. We're going from 2% in the unlogged areas to 15% or so after logging, and then up to 25% or 30% with slash burning. So, again, the burning is not just an aesthetic problem. There is a fair increase in mineral soil exposure—so there is a potential for erosion.

Question *(Unidentified)*: I would like to ask Al Edie if he would mind explaining a bit more about the concept of single use as opposed to multiple use, particularly if in the future we are going to have to make decisions for fish or for lumber or both?

Answer *(W. Young)*: You've only got two hours to answer that question.

Answer *(A. Edie)*: It'll only take me a few minutes. I think that over the last several years of us dealing with the forest industry and them dealing with us, we've gradually boxed ourselves into a lot of areas that have been the last things on the agenda to be developed. Riley Creek and a few of the other creeks on the Queen Charlottes are, I think, fairly good examples. And I think that, in some of these watersheds and perhaps in some portions of different types of watersheds, we really have to deal with the question of whether or not we can log them all and still have fish. And I'm not at all saying in that comment that we should necessarily make the decision in favor of the fish. I think that, in some of the areas for which we are not forced to plan, we've got to start dealing with the real issue, the real question—"which one do we want"—because it may well be that we're not going to have both, no matter how hard we try.

WATERSHED USE AND PLANNING--WHAT THE MANAGERS NEED TO KNOW

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Mr. Chairman, fellow speakers, ladies and gentlemen. I would first like to express my appreciation for the opportunity to speak today and my thanks especially to Dr. Gordon Hartman for his huge efforts and also to the other organizers, speakers, and participants whose keen interest and hard work have made this valuable workshop possible.

It has been a long agenda, so I'll be brief. I will do three things in my presentation:

1. Explain why my section of the Fish and Wildlife Branch needs information about small streams and what kind of information we need.
2. Briefly indicate what I think we now have from Carnation Creek and how we can use it.
3. Throw in my nickel's worth about where studies should go from here.

Protection of fish habitat is one of the main objectives of the Fish and Wildlife Branch. We in the Habitat Protection Section pursue this objective largely by providing suggestions in various planning forums as to the likely impacts of development proposals and as to how to mitigate or avoid those impacts.

In these planning activities, our most productive and commonly used approach is to suggest how to do it, rather than to say don't do it. In the real world of diesel, steel cable, and fish, these suggestions must be specific, clear, and feasible--or they will be useless. If they are to help fish, they must also be ecologically sound. This is where Carnation Creek can help us. We need solid ecological information--information that can support confident choices between land-use alternatives, information that enables provision of specific, feasible constraints or techniques for mitigating impacts, or sometimes, information that can clearly identify circumstances under which particular developments are totally incompatible with fish habitat.

Information not useful in these terms will not help us protect habitat.

So much for the kind of information we need. I would now like to address the second topic I mentioned earlier, which is the information we can now get from Carnation Creek and how we can use it.

From the papers we have heard, it is clear that results are preliminary, that additional information and analysis is necessary, and perhaps especially that Carnation Creek is not yet finished responding to logging activities. Dr. Gordon Hartman did an enviable job yesterday of pointing out the complexities of interactions between fish and forestry in Carnation Creek, and he, I think correctly, pointed out the dangers of early generalizations on incomplete data.

However, I think at least one message is already clear. Physical suitability of Carnation Creek, and coastal systems like it, for production of coho, and probably steelhead and cutthroat trout, is very much an expression of the profound influence of stable large organic debris in the stream channel. This debris and the mosaic of habitat it provides depend on a dynamic equilibrium between the hydraulic forces of streamflow and the ability of the debris and stream channel to resist them. The response of the stream channel in the logged sections of Carnation Creek has clearly demonstrated that this equilibrium can be sensitive. Just how sensitive remains to be seen. It is distinctly possible that the channel changes to date are merely the initial crumbling of the dyke after the thumb is removed from the hole. Downstream impacts of the instability induced by logging in reaches VI and VII may continue for a long time yet.

Recognition of the sensitive equilibrium provided by stable organic debris in a stream channel has obvious management implications, namely, that, if logging is to be performed without serious implications for fish, channel morphology and the debris upon which it depends must not be disrupted by logging operations. Numerous site-specific prescriptions follow logically from this objective, but the obvious general techniques are to leave stable debris in and adjacent to streams where it is and to avoid adding small debris to the channel either directly or through tributaries.

The real challenge will be to somehow ensure a long-term source of debris for small stream channels, especially in locations where severe windthrow conditions prevent leaving strips of old-growth timber along streams. It is possible that the only option in some high-conflict watersheds will be permanent programs of debris or rock placement to replace the effects of gradual introduction of large tree debris from old-growth forests. As usual, the question will be "who pays?"

I think I will leave my comments on information now available from Carnation Creek at that, to emphasize the apparent importance of stream-channel stability and integrity.

Now I would like to put in my two bits about where we go from here.

I would like the Carnation Creek project to finish up on two more or less distinct fronts. The first is to follow through and complete existing studies over the postlogging period. There are numerous specific investigations that we are interested in seeing continued, but I will not try to list them all here. The major issue of interest to us is the debris and stream-channel stability work. We definitely would like to see careful monitoring of channel morphology downstream of reaches VI and VII to document fully the downstream impacts of destabilization of these logged reaches. Consideration of the potential role of bridge crossings in inducing this kind of stream instability would also be useful. The last item I will mention here is that we would definitely like to see clarification of the mechanisms behind the apparent decline of steelhead and cutthroat trout.

The second major thrust in continuing studies should be toward improving our ability to confidently extrapolate results to other coastal watersheds and, perhaps, to some interior ones as well. The first task is to recognize and explore the major differences between Carnation Creek and other coastal watersheds that we deal with. One such difference is likely the role of snowmelt in peak streamflows and the potential for logging to increase peak flows by increasing the rate of snowmelt in clearcuts. Another such difference may be the degree to which interference with small hillside tributaries can cause large increases in main-stem bedload and subsequently large changes in channel stability and morphology. No doubt there are other potentially major differences as well. The task will be to consider them, compile existing information on them, perhaps undertake additional work on them, and finally produce educated guesses on how they should affect extrapolation of results to watersheds obviously different from Carnation Creek.

Another task regarding our ability to extrapolate may be to produce a set of key variables or indices which can be measured quickly and can be used as an aid to predicting the degree to which other streams can be expected to behave as Carnation Creek did. Factors such as stream gradient, channel structure, loading with stable debris, and valley shape are obvious examples.

I must emphasize that attention to our ability to extrapolate is critically important. We can, we must, and we will extrapolate; the only question is how sensitive and accurate the tools we will use will be.

I would like to close my presentation with a few words of perspective. It was nearly a decade ago when the Select Standing Committee on Fisheries and Forestry suggested that fisheries agencies become involved in the planning of forestry activities. Since then, we have planned by referrals, by folios, by coordinated resource plans, by watershed preassessment, and by numerous other mechanisms not endowed with their own names. We have endured perpetual argument about single use, multiple use, integrated use, and no use. Through it all, much time and effort seems to have been spent in a never-ending search for the elusive perfect planning system which, coupled with nearly perfect information, would forever deliver us from this tangle of resource conflicts.

Some individuals of a planning persuasion still look to the 1980s for if not the perfect planning system and the bureaucratic bliss it will surely bring then for at least a gradual reduction of conflicts as planning mechanisms become more sensitive and more information such as that from the Carnation Creek study become available.

I urge anyone with such notions to take off their rose-colored glasses and look again. Close to ten years of planning have not resulted in a substantial reduction in conflict—just changes in some of the details. Indeed in some locations, such as in steep areas of the Queen Charlottes, the conflicts are more intense now then ever and are likely going to get worse. Further, it is fair to assume that the general trend of forestry operations moving into more difficult terrain to harvest poorer-quality timber at greater cost and with more significant environmental constraints will continue through the 1980s. Such a climate will undoubtedly generate substantial pressure for general relaxation of constraints and for harvest of many locations "deferred" when industrial backs were not pressed quite so tightly to the financial wall. We can expect heightened resistance to any constraints that mean extra costs, and we can expect far more intense scrutiny of the bases for our recommendations of their results, and of the cost effectiveness of all our inventory and planning activities.

Far from being easier, planning in the rest of the 1980s will probably present us with the most awesome challenges we in the habitat business have yet faced.

I suggest that, in using information from the Carnation Creek study to tackle these challenges, our efforts would benefit by the laying to rest of two myths.

The first myth is that habitat limits all, or most, of our salmonid populations. I think our credibility as resource agencies in the changing resource-management climate of the 1980s would be greatly enhanced if we would visibly admit that, in many systems, stock management—not habitat loss—may be the problem with fish populations. Further, in systems with stock management problems, we should be prepared to do something about the problems or to consider adjusting our habitat recommendations accordingly. It is patently unreasonable to expect the same degree of protection whether or not habitat is vacant, and we can bet our chest waders that managers are soon going to hear this argument a lot more often than we have in the past.

The second myth is that integrated use, or multiple use, or whatever you wish to call it, should or can occur on every acre of this province. I think it is high time that resource managers, resource users, and politicians all wake up to and deal with the fact that some acres of this province may be able to produce fish or wood, but not both. For too long, we have been hiding under the planning umbrella eating our resource cake and assuming that we can keep it too.

I believe that the real challenge for resource management in the 1980s will be the formulation of a rational decision-making process not for integrating land uses but for deciding between them.

To summarize, we need and we can get from the Carnation Creek study hard ecological information on which to base decisions. The main issue clarified so far is the role of stream-channel stability in fish production. As the project draws to a close, we would like to see emphasis on further clarification of the channel-stability issue and specific effort expended to increase our ability to extrapolate to other watersheds.

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The subject of this presentation is watershed use and planning, specifically, what Field Services personnel (i.e., the local fishery officer) need to know and in which facets the Carnation Creek project has made available this information.

The dedication of watershed usage is complexed by many variables. It is suffice to say that socioeconomic evaluation is a prime determinant to this process, which is far removed from the operational level to the political arena of respective provincial and federal governmental forums. In essence, the fishery officer is not perplexed with the problem of whether or not to harvest the forest of a watershed within his or her jurisdiction, but rather with the fashion in which these activities be conducted.

Under the present referral system, once an area is slated for logging, the officer must identify the fishery resources within the requested watershed, being concerned with escapement by species, timing of migration patterns of returning adults and seaward-moving juveniles, barriers to migration, and the migration, spawning, and rearing areas of those anadromous salmonids present. This is the data base the officer utilizes when making value judgements regarding forest-harvesting practices, both in the method of operation (e.g., falling and yarding constraints) and the timing of certain activities (e.g., stream crossings).

When reviewing 5-year developmental plans submitted by the forest company for a particular watershed, the opening or "setting" sizes and tentative timing schedules are initially considered as determinants of the amount and rate of cut. However, the ability to comment upon dispersion of logging patterns (and the avoidance of rapid removal of timber) so as to minimize detrimental hydrological changes must be based on a sound understanding of complex, interacting variables that, for the most part, are beyond the scope of a fishery officer's working knowledge. At this stage of analyses, the Carnation Creek study has shown that, for about 41% of the watershed having been clearcut, there is no clear evidence that clearcutting of this magnitude has caused changes in the relationship of runoff to precipitation (i.e., the storm-hydrograph peak flow or time-to-peak characteristics) in the main creek or in the annual water yield in the total system. At what extent of clearcutting, in terms of timing and amount, are hydrological changes elicited that are worthy of consideration for a nonfish-bearing system similar in overall characteristics to Carnation Creek?

The second major consideration when reviewing 5-year plans is the proximity of logging operations to both fish-bearing watercourses and waters leading to fish-bearing watercourses.

In many instances, major stream systems are incorporated into natural falling boundaries for the various openings. Protection along these stream systems, particularly where fisheries resource values are established, is of primary concern at the planning stages.

Fishery officers have long since recognized the severity of intensive falling and yarding procedures when conducted alongside or near watercourses, as has been borne out by the Carnation Creek study. Although some clarification is still required on "P Clause" logging, this guideline, by and large, has ensured maintenance of what has appeared as short-term, satisfactory water-quality standards and increased protection to streambanks and channels. Implementation of directional falling and yarding techniques allows maximum forestry yield while attempting to preserve the fisheries resource.

But not only main-stem river and stream systems need to be preserved in as natural a state as possible. The significance of small intermittent tributaries and side channels has been illustrated by the Carnation Creek study. Where the importance of these watercourses is determined from on-site inspections, directional falling and yarding, where practical, as well as cleaning up small chunk debris within the highest wetted perimeter have been requested. The latter condition is easily met, at cost, while directional falling and yarding may not be possible owing to the sinuosity of these systems, local topography, and preferred landing locations. At present, the Department of Fisheries and Oceans (DFO) takes a firm stance on the preservation of these summer-rearing and/or overwintering habitat, and consideration must be given for leaving some merchantable timber standing.

Protection of nonfish-bearing watercourses which empty into waters inhabited by the salmonid species for at least part of their life cycle is warranted to maintain downstream water quality. Debris sluiceouts arising from the debris deposited during intensive falling and yarding practices or from streambank destruction leading to sedimentation effects have virtually eliminated consideration of any cross-stream yarding proposals, or where permitted across some intermittent and ephemeral systems of headwater drainages, necessitated concerted efforts towards yarding debris cleanup and restricted or modified yarding practices. These measures are, at best, only stop-gap and, by no means, all-protective of the downstream fishery resources. Studies similar to Carnation Creek should also place emphasis on the specific effects generated downstream by intensive logging practices on such nonfish-bearing systems, in order to serve as a guide to fishery and forestry managers when devising cutblock layouts, landing locations, etc.

It is apparent from the Carnation Creek study that information is still deficient of the role that riparian vegetation plays in leaf-litter input and, hence, detritus production. Alder treatment programs, both for conifer release and as measures against anticipated seed-in of recently logged areas, are being referred to DFO at an ever-increasing rate. Although in some instances the method of treatment is of concern for the protection of the fishery resource which can be more or less easily resolved (e.g., herbicide versus mechanical treatment), the main area of contention involves the volume of streamside vegetation that can be eliminated before the system's level of productivity is significantly altered. Present guidelines are sadly lacking in this regard, with the problem compounded by the fact that some forest operations have been treating streamside alder prior to logging (e.g., by girdling techniques).

The third major consideration when reviewing 5-year developmental plans is that of the amount and location of forest roads and stream crossings.

Generally speaking, economics dictate the shortest route from stump to dump. However, preferred grades may locate many road works in proximity to watercourses. Stream encroachment and blasted overburden ending up in watercourses still occurs.

While the Carnation Creek study documented very graphically the net effect of forest road construction, logging, and silvicultural treatments upon gravel quality in the lower 2 km of the main-stem stream, isolation of the long-term generation of sediment from forest roads alone was not feasible owing to the nature of the program.

The impacts upon the aquatic environment generated during road construction are well recognized, if not documented, particularly when these activities are conducted under harsh weather conditions. During the winter months, low-elevation road construction proceeds with men and machinery that are "snowed-out" of the higher-elevation summer shows, having the potential for impact upon adjacent watercourses. DFO has little or no control over these activities but is involved more precisely with the timing and construction requirements for stream crossings only.

Again, the fishery officer has little control over the amount of soils radically destabilized by cut and fill operations, except for identified problem areas where these activities would proceed directly beside watercourses or involve drainages that lead directly to fish-bearing streams. A similar approach has been given to end-haul locations.

Sediment transport via road ditches has only been briefly addressed by DFO. In some instances where ditch flows enter direct to fish-bearing watercourses, sediment traps have been requested. For the most part, though, ditch works and crossdrainages liberate undetermined quantities of sediment derived from road washing, from scouring, and from ravelling of cut slopes to adjacent and nearby watercourses. The significance of vegetative filter strips between road works and streams has not been clearly established and requires clarification.

One area of endeavor that the fishery officer has little input into is that of road and culvert maintenance, except on a reaction basis when there is failure (e.g., mass wasting with sedimentation impacts to nearby watercourses). Regarding bridges and culverts, the officer gives recommendations as to opening sizes that will accommodate flood waters. However, as has been illustrated by the Carnation Creek study, these structures should also be designed to allow the passage of large organic debris. Generally speaking, bridge crossings over main-stem systems will permit free travel of large debris, but smaller culverts and pipes obviously will not. Maintenance of these structures is a realized problem, and for some potential debris-movement areas, local officers have requested debris catches to be installed.

The Carnation Creek study has also shown that debris movements continue for at least three years after logging. Debris clearing from around blocked culverts on mainline and haul roads is usually, but not always, quickly recognized and completed before major failure occurs. However, past situations have shown little attention paid to disused spur roads. Some of these former active roadworks are left forgotten in the natural state as requested for access for fire equipment if ever needed, while others are "put to bed". The latter procedure, involving the removal of culverts, destabilizes local soils with a washing of sediment over time until a steady-state system is eventually reached. Existing roadworks in the Carnation Creek study area would present an opportunity for future consideration into these matters.

Continual road-maintenance programs (e.g., grading and filling) are required to keep the roads in a passable condition and reduce wear on logging and other trucks. Winter rains literally wash the roads away, while grading programs aggravate the problem to a certain extent by recurrent destabilization of the road surface. In-filling of road ditches (which illustrates sediment transport in some areas) requires excavation programs (which also lead to destabilization of ditches and banks). These problems should be quantified for a more meaningful understanding of the impacts of forest roads on the aquatic environment, particularly where these roads are located in juxtaposition to watercourses.

And lastly, although not usually contained in an officer's initial comments regarding the developmental plans, is the consideration of silvicultural techniques.

The aspects of alder removal and detritus production have been discussed. Additionally, it was found in the Carnation Creek study that many of the alder that were treated with biocides and then felled due to typical yarding problems entered into the stream channel to form a substantial part of the debris jams within this system. Girdling techniques have shown similar results when overzealous crews have cut away too much supportive wood.

Two facets of silvicultural treatments, namely herbicide and fertilizer application, would lend themselves to observation of their effects upon water quality and the aquatic environment in the following years of this study.

Importantly, the Carnation Creek study has quantified the increased degree of soil disturbance attributable to slash burning and scarification, although quantities of sediment resulting from each of these causes that are contributed to overall sediment release to the system were not determined. At this point in time, how the local fishery officer can temper his judgement towards these two programs when reviewing forestry practices is not clearly defined. Further research in this area is definitely needed.

In summary, the Carnation Creek study was essentially designed to determine the compatability of fisheries and forestry as multiple watershed-resource users with the objective of forest-fisheries planning to minimize adverse effects and capitalize on those that are not. This is an admirable adventure and should command the attention and respect of all interested parties.

It can be superficially surmised that DFO operational field personnel can only construe from the findings of the Carnation Creek study that fisheries and currently practiced forest-harvesting and silvicultural techniques are, in fact, not compatible. As shown for bank erosion, channel instability, reduction of the volume and stability of in-stream debris, alterations to gravel quality, and reduction in egg-to-fry survival, the long-term net benefits derived from increased biological productivity due to canopy removal or higher nutrient concentrations after logging are indeed questionable.

However, fish-forestry interactions are not black and white. The Carnation Creek study has shown some grey areas. In the end result, protection of the fisheries resource once again is determined by application in the field of the available scientific knowledge, practical experience, and the ability to "wing it" in the face of what may appear as unsurmountable odds.

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To reiterate, the Carnation Creek Project was set up as a multidisciplinary study of a small west coast rain-forest watershed and the effects of logging upon it. The three broad objectives of the study are:

1. To establish a strong understanding of processes and interaction, physical and biological, in a typical small watershed in a west coast rain-forest area.
2. To obtain information of the effects of specified logging and postlogging treatments on such a system.
3. To communicate information to forest and fishing managers and planners in order to improve planning and regulations of activities within watersheds. The basic intention is to benefit both fisheries and forest activities.

The past two days have provided a forum for the presentation of physical and biological data collected over the preceding ten years. Today affords the opportunity to review the management implications of the data presented. The two areas I will pursue, in relation to the topic assigned, are:

1. Perception of needs or information prior to planning of a harvesting plan in a watershed. The impact or knowledge gained from the Carnation Creek study.
2. Problems and concerns of a project such as Carnation Creek in relation to other watersheds.

What information do planners and managers need to know in providing a harvesting plan in a watershed? Briefly, there are five elements that need to be known in providing a harvesting plan:

1. Timber types and grades. Basically, this information is required to determine profitability, given various costs and constraints in harvesting.
2. Soil stability. A geotechnic report, if possible, will provide information for road location, construction methods, and potential problem areas in the watershed.
3. Climate conditions. Annual rainfall, prevailing winds, and exposures.
4. Stream characteristics and fish resources. Simply, if you are planning, you have to know the various fish species, their characteristics, and which areas of the stream that are vital for fish habitat.
5. Wildlife. Species, population, and requirements.

The impact or knowledge gained from the Carnation Creek study, to varying degrees, will lead to a reassessment of development and harvesting plans. Logging in this watershed has had an impact—and, to a degree, a positive impact—within the time frame we are looking at. By positive, I mean a negligible impact on enhanced opportunities through harvesting of timber.

Examples of positive impacts are:

1. Sequential Harvesting or Progressive Clearcut. Carnation Creek is a relatively low-elevation high rainfall (215 cm to 350 cm per year) watershed. Most individuals would have expected that sediment introduced into the stream would be greatly increased by road construction in the winter months and clear-cut logging. Through clearcutting, the mineral soil was exposed, other vegetative or riparian cover reduced, and the other protective features of the organic mat altered; thus, with a high annual rainfall, introducing sediment into Carnation Creek. However, with the introduction of logging slash, natural growth, and the planting of seedlings, the increase in mineral-soil exposure did not increase significantly after the first rainy winter.
2. Slash Burning. Messrs. Smith and Wass concluded that slash burning presents a higher visual than physical impact. I would have expected a significant increase in mineral-soil exposure, a decrease in the protective organic mat, and a reduced opportunity for reforestation. This assumption is not evident.
3. In-stream Activities. In-stream activities I define as placement of culverts, bridges, and approachways thereto. The Carnation Creek study quantified the levels of sediment introduced into the stream by these activities: how much sediment was introduced and how long it lasted. The results showed there to be an insignificant impact if the work is carried out in a good workmanlike manner during the proper time periods.

One setting RR8 (containing reaches V, VI, and VII) has to be viewed in a positive light. This setting, you may recall, received extreme logging treatment by felling "merch" and "nonmerch" trees to the streambank, felling trees in the creek, yarding logs through the creek, and removing stable logs from the creek. This logging practice has been abandoned for a number of years. This treatment, however, did allow the scientists and technicians the opportunity to quantify the impact of such a practice on a stream—the fish habitat and the aquatic life within it. Part of the Carnation Creek study was extended for that purpose—gauge the impact! A concern with this method is that it tends to discolor the other positive aspects of logging by the magnitude of damage to fish habitat: (1) streambank erosion causing siltation of spawning, (2) removal or filling up of pools through siltation, and (3) reduction of overwintering sites for one year plus coho and steelhead by removal of stable organic debris.

The other aspect of this paper deals with problems or concerns on a project such as Carnation Creek in relation to other watersheds.

Typical Small Watershed

I guess the first concern would be the term "typical". Carnation Creek is typical of many small watersheds on the west coast of Vancouver Island. Carnation Creek is a narrow, shallow creek in relation to other major streams or rivers. The soil conditions indicate a relatively stable watershed, although three minor slumps have occurred in the month of January 1982. Two of these three slumps appear to be logging-induced, while the third occurred in a windfall patch.

Carnation Creek watershed, instead of being an independent stream flowing into an inlet, could conceivably be a large tributary of a major river. Also various aspects of Carnation Creek may relate or be similar to a section of a major river. The point I am trying to make is that information or knowledge gained from the study cannot and should not be extrapolated in its entirety to other watersheds. The information gained should be on a site-specific basis, given the characteristics being similar.

Streamside, Tributary, and Side-Channel Management

Management of the land area next to the stream or watercourses is the most significant concern of the Carnation Creek study. It is also the area that poses that greatest number of unanswered questions. I would suggest the P-1 clause of the Ministry of Forests is perhaps the best alternative at the present time on a site-specific basis. Merchantable timber within a one-chain strip of the stream is to be removed at a minimal impact to the nonmerch trees or riparian vegetation. Slash burning or scarification should be also removed one chain from the stream. This method should ensure the integrity of the streambank and minimize siltation.

Within the realm of streamside management falls the question of alder trees and salmonberry brush which are prevalent in most west coast watersheds. How to manage these tree and brush species poses conflicts within a fisheries-forestry content. Alder and salmonberry provide a requirement for the benthic community of the stream, as well as stabilizing the streambank. The land area next to the stream is usually the most productive, high-site index areas. If salmonberry or alder is left unchecked, this land can be quickly lost to conifer production or the conifer regeneration subdued by the quick-growing weed species. The optimum balance for both resources is not evident and a number of questions still remain:

1. The degree of riparian vegetation or alder required to fulfill the benthic requirement of the stream.
2. Can a substitute for alder be introduced that will provide the benthic requirement and reduce the loss of high-site index lands?
3. At what time frame will nonmerch conifer or reforested area provide the requirements of the stream or will it ever?

Clear-Cut Logging On Stream Temperatures and Nutrient Levels

Dr. Hartman has indicated that clear-cut logging has increased the relative water temperature of the stream and Scrivener and Stockner and Shortreed in their papers have shown that the nutrient level of Carnation Creek has been enhanced by logging. These factors, combined with stronger illumination, have had a positive impact on the growth rates of fry in the first year.

The warmer temperatures of the stream have, however, caused the coho fry to emerge sooner than previously and were subject to freshet conditions and subsequently lost to the system by being swept out to the estuary. On the other hand, the number and size of coho smolts escaping to the inlet have increased significantly. Can the system be managed more effectively or, again, where is the optimum balance between fry or smolt production? Can the stream be enhanced to provide an increase in production of smolts and fry?

Future Scope or Directions

The Carnation Creek study is two-thirds complete. During this time period, an impressive data bank has been accumulated on the watershed. The impacts of logging have been well documented. The second cycle of forestry has started, and I feel the various treatments of these practices, I am referring to are the use of herbicides for seed tree control and release, as well as the use of fertilizers to advance reforestation. Both these practices are controversial to varying degrees. The beneficial impacts on their use is known for forestry purposes. The potential impact on the fisheries resource by altering the natural process in the watershed is unknown.

The interpretation of the information we have will provide us with opportunities for better habitat management and enhancement in the future.

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I would like to start off by saying that I am not the greatest expert on Carnation Creek, but after the last two days, I am rapidly becoming a lot more familiar with the issues, background, and scientific knowledge that is now available. I am very impressed by the papers presented here and the entire Carnation Creek project. The sincerity and enthusiasm is great.

I have certainly learned a lot in the last two days, even though I may not have digested the majority of the information.

The buzz words used here have been fantastic. To mention only a few: water years, micro gram atoms, algal biomass, Julian date, and benthic foragers (my favorite).

The kind of baseline studies we have seen in the last few days are absolutely essential to our better understanding of forest and stream ecosystem dynamics. The information we get from these studies helps us do a better job of planning and managing our forest and fisheries resources.

Conflicts between resources are becoming a way of life as competition develops between users. The more we learn of the interactions between resources and also of our own resource, the less chance there is for conflict—or at least it seems easier to find a compromise. My experience with the Integrated Wildlife and Intensive Forestry Research Project around Campbell River has shown me the truth of that.

The more time we spend talking and researching our problems, the better off we are.

What do we need to know to do our jobs? The B.C. Forest Service is a land and forest manager, but is also a government agency and a reviewer and approver of industrial operations. In many cases, it is also the decision maker on whether to proceed on an operation or not. We must have a good understanding of the ecosystem dynamics. Sound studies like Carnation Creek are needed to give us confidence to make decisions—in the right direction.

Referral System

There is a system in place at present to handle various resource concerns. Whether logging takes place on TFLs or forest licences or other tenures, the licencee is required to submit a five-year development plan—basically maps 1:20 000 showing the cutblock boundaries, the annual logging schedule, and any other concerns (e.g., wildlife winter range, streamside concerns).

There is a referral system to other government agencies, and as a result of discussions, modifications are made as required.

Before logging actually takes place, a cutting permit is required. The cutting permit contains various clauses that cover all of the concerns in the specific cutblock.

As we learn more about management of our various resources, the guidelines and cutting permit clauses should be reviewed and changed.

Maybe we are at this stage with our P-1 clause, now.

The question "What are the impacts of specific forest-management activities on a stream ecosystem" must be answered if we are to do our job.

I would like to go over some of the points we have covered in the last two days.

Streamside Treatment

This is a critical area of fish-forest interaction. Do we leave a strip of timber along the creek? or Do we log straight through the creek? There is valuable timber along the creek that we would like to remove. If left, the timber may blow down anyway. Alder is a special problem. We would like to remove the alder seed-tree threat and prevent alder from seeding into our clear-cut areas.

After listening to the discussions here in the last two days, it is obvious that streamside management is a must. Streamside equilibrium must be maintained and large organic debris must be managed. Natural backwaters and side channels should be noted and preserved.

This is an area that we must keep working on, and as I said before, maybe it is time to review the P-1 clause and existing guidelines.

Road Building

We now have a better understanding of how roads and road-construction activities impact on the streamflows and the entire watershed. How we build roads and put in drainage structures to minimize the impact on the watershed are important.

We have learned that there was only a small increase in annual water yield and that peak flows were increased after logging, but not after road building. We also learned that logging 40% of a watershed in six years has not greatly affected the streamflows.

Logging Openings

We have learned that clear-cut logging affects water movement, storage, streamflows, etc.—but only marginally.

A point that I would like to make is that, in the short-term after logging, people have a gut feeling that a disaster has occurred. We need studies like Carnation Creek to prove to people that it is not so.

If people went to Carnation Creek or saw some of the slides here (pictures) or the logging and slash burning, we would get cries of "my god, what a disaster". But not true—the scientific studies at Carnation Creek show that there is no disaster, there is no great erosion problems, and there is no great change in annual water yield or peak flows.

There are even some positive effects of logging.

Slash Burning

The effect of slash burning on a logged area must be examined. We have learned here that there is an increase in nutrients in the stream after logging and slash burning.

We would like to keep some of those nutrients back on the hillside for the trees. From a forestry point of view, we are asking how much site degradation is caused by the slash burning. It is a hot issue right now. A workshop is planned for March on this very topic.

Vegetation succession following logging is of great interest. The proliferation of salmonberry and other brush is good for fish habitat, but not for forest management.

High-Site Management

Our best forestland—the best growth—is usually in the valley bottom and we have great concern for brush problems, alder and salmonberry, etc. We must plant large seedlings immediately after logging and continue to brush and weed these trees until they are above the brush. Aerial herbicide treatment is usually required to beat the brush.

I would be interested to know what the stocking is in Carnation Creek. What area has been planted or restocked naturally on both the flats and the sidehills with the rocks hanging out.

Second-Growth Management Treatments

As a second-growth forest develops, the effects of various treatments must be noted on the watershed ecosystem.

Plantation establishment, use of herbicides for brush control, juvenile spacing, aerial fertilizer application, commercial thinning operations, and, again, the clear-cut logging of the second rotation of timber—all influence the watershed.

Fisheries people will learn a little about forestry—and not just the end of a chainsaw. After harvesting comes tree planting and a new forest, and that is what we are about to see at Carnation Creek.

Rate of Cut

The rate of harvesting in the watershed affects the dynamics of the watershed. In a six-year period, 41% of the watershed has been logged. The results of this study will provide us with some very interesting results.

Comments

This study has enabled forest managers such as ourselves to understand better the impacts of forest harvesting and management activities on stream environments (e.g., depositing large debris in a creek may enhance fish habitat, rather than damage it). Seasonal channels are critical to overwintering fry, hence, harvesting activities must recognize and protect them accordingly. It should also assist in the development of sound, practical guidelines for watershed management based on firm quantitative data.

To the Ministry of Forests, the continuation of this project, now that it is in the monitoring stage, will be of utmost interest to us. We should be getting quantitative results from various harvesting and management disturbances on the watershed. As forestland managers, we need to know the impacts, if any, on the stream ecosystem by our planned activities.

There are several shortfalls to the Carnation Creek study. Due to the low elevation of the watershed, there is very little influence of snow or snowpack. Also, there is a lack of problem-soil types and steep slopes that would cause unstable conditions and serious erosion problems.

And a final comment, in view of time, manpower, and dollars required in carrying out the Carnation Creek study, it is doubtful that a similar study of this magnitude can be carried out again. Compounding the problem is the fact that untouched watersheds of adequate size, suitability, and access have become more scarce, so we'll have to get as many kilometres as possible from this study. The B.C. Forest Service strongly supports the continuation of this study and follows it with great interest.

CONCLUDING DISCUSSION

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We are now at the last part of the session and we are going to get Dave Narver, who, as you all know, was involved in the early stages of development of this project, to speak again. He has some things that I think you should hear. The other person you are going to hear is Jim Hall. He was a key person in the whole Alsea watershed study. We feel that, at this last part of our session, Jim will have some particularly valuable observations to make for us. The next thing I want to do is to indicate to you what I hope will come from this work and meeting. We hope to publish a "proceedings". They will not be elegant. We will bind the papers and as much as possible the questions, answers, and discussion. I am not going to make a prediction as to when the proceedings will come out. It will take me some time but we will be working on it. We will attempt to get the proceedings widely distributed to government and industry management people along the coast of B.C. We are going to disperse the information in that way. In the light of the fact that we are in the last phase of the study, I would like to have a lot of the following discussion focus to give us direction for the future. I think you should feel free to have discussions to try and sort out things between yourselves and the people who have given papers, if there are still things that you would like to talk about.

The last thing that I am going to say has been repeated here pretty often. It is that this process that we have gone through was called a "10-Year Review Meeting and Workshop". We have called it that because "all of the answers are not in". There may be new information in the future and there may be changing perceptions of what is coming from this project. I would really like everyone to keep that in mind. The second thing that I would emphasize again is that we, as researchers, are first of all interested in understanding watershed processes. It really doesn't matter whether you are working at the end at which Eugene Hetherington works, starting with the water which is one of the essential ingredients in the system, or if you are right through at the other end working with fish or chironomids in the bottom of the stream. We are concerned with processes and I think that it is imperative that management people take away an understanding of the processes. It's imperative that you take that away and try to use whatever understanding you get from this session and the proceedings, in the context of your experience and in the context of different situations with which you are going to have to work. I would say, in the name of whatever, don't go away thinking that, because 41% of this watershed is cut and we haven't detected what is regarded as significant hydrological changes in a certain context, this means that 41% of every watershed can be cut without any changes. That is exactly the kind of dangerous oversimplification I think people really must avoid. I could rephrase that exhortation, giving any number of other examples. Try to use the information about the changes that have taken place in the context of each new situation. As I said before, the manager becomes an absolutely crucial person doing this. The manager is out there; he or she understands each of these new situations better than I do or better than the working group people do. We are only a part of the process. So I just can't stress strongly enough that Carnation Creek should give you an understanding of processes and not a recipe book. If you use it as a recipe book, then there will be "hell to pay" in some situations, and I think fairly quickly. I stress this point in particular because I'm sure that, if this project had been carried out in a radically different sort of watershed (for example, if we have carried it out in watersheds on the Queen Charlotte Islands), we might be finding that, as someone here already pointed out, there are other things of major significance. I think that, rightly so, Jeff Cederholm pointed out to us the significance of debris, channel morphology, and fluvial processes and the implications of these things to streamside management, and that is where a lot of the action is. That is where I think the significant processes are that we've identified to date in Carnation Creek. But I'm quite sure that, if we had been dealing with a watershed on the Charlottes and perhaps one that went straight up on either side and had very different kinds and depths of soil, we might be identifying other processes as being important. I hope that, once we get further into it, we can start laying our work down alongside the work of Vince Poulin's Queen Charlotte Project. In this way, we can really expand understanding and appreciate this point even better. We have one person here from the Salmon Commission who's been working with the Nadina River in interior B.C. I think it is obvious that, if we were involved with this project in such a location, we would see different processes and different problems. Some of the things we think should be done here would not be applicable there. People may not like this, but it is a reality of the diversity of natural systems. It's important that we recognize this. I think that's all I wanted to say. I was going to talk about the implications of the work to management; however, that will be written and will be in the proceedings. You can look at it there or quiz me about it, if you think it's important. I would like to ask Dave Narver and Jim Hall to come up. They will make some remarks and then I think that, again, we will simply open the whole meeting up for questions back and forth across the floor or to us or wherever you want. We'll go to about 3:00 or 3:15. If you feel that it is desirable to stop sooner, we will do so.

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I want to offer a few warnings and challenges to Gordon Hartman and the current Carnation Creek workers. I'm here after 3 days, tired like the rest of you and with a lot of mixed emotions. I think the first thought I want to share with you right now is the realization that a lot of you other graybeards were with me at the end of the 1960s and in the early 1970s, going around the province talking to people about how streams work and what the possible impacts were from logging in coastal watersheds. But, of course, we used information gained mainly from other studies or textbook examples.

My overall reaction after these 3 days of intensively looking at the Carnation Creek study is that I'm not too surprised at the kind of results that are appearing so far. Particularly, the strong indication of the importance of stable streambanks. That is something that we fisheries biologists have been concerned about for years and years. It is sure nice to have some home-grown hard information on the value of streambank stability and associated debris.

In 1971, Dr. John Mason and I published something that we called the "Research Needs in Stream Ecology". We made four points in this paper based on input from a lot of stream ecologists of the day. The first of the four research needs was for controlled studies. We saw that Linda Berg and Norm Ringstad, for example, made use of that kind of controlled environment in the intensive study of a particular biological phenomenon. John Mason had studies in mind that required a controlled stream environment that was about one hundred feet long. While we were unable to get funding, at least part of that first concept has been part of Carnation Creek and other studies adding to our knowledge about how streams work. Second, we identified a need for short-term studies. Geoff Cederholm advised Gordon Hartman this morning of the need to do short-term upstream-downstream kinds of studies in wild streams. Third, we identified the need for long-term watershed studies such as the Carnation Creek and Alsea projects. And fourth, we believed that a synoptic survey to assess a few parameters over a wide range of watersheds and treatments may be the approach necessary to extrapolate results from Carnation Creek to other sites. Mason and I stressed that these four thrusts must be made in order to substantially improve our knowledge about how stream systems work. I'll just remind you that we identified these four research thrusts some 13 years ago, and to some degree of faithfulness, they have been pursued in the Carnation Creek project and other studies over the past 10 years.

As a researcher for 15 years and as the coordinator-administrator of management and enhancement programs in provincial fisheries for the last 7 years, I charge Gordon and the Carnation Creek working group to remember who is it that has the ultimate interest in the results of this study. You're not doing science for the sake of good science. We have 500 000 freshwater anglers in B.C. and 300 000 saltwater anglers. People in B.C. think fish are neat; fish are part of their cultural heritage. The commercial fishing industry and the whole forest industry is dependent on streams. Those are the client groups we must keep in mind in this study.

I had some impression, toward the end of yesterday, that some of those working on fish problems might be looking at their fish data in isolation of work going on elsewhere. I hope noone is waiting to publish material because the fish-stream scene in British Columbia is developing too fast. Our knowledge of streams and fish, the impacts of other resource developments, how to enhance fish production, and the population dynamics of stream salmonids is very much wider than Carnation Creek.

I hope that the Carnation Creek workers are in close contact with Pat Slaney and his population dynamics knowledge of coho, Dolly Varden and steelhead from the work for the last 6 years at the Keogh River. In western North America, the long-term studies of fenced streams like Carnation Creek are extremely rare and, of course, expensive. We've only got three in the northwest: Carnation Creek, Keogh River, and Snow Creek near Port Townsend, Washington. However, data from these studies are what we really need for comparative purposes and to really understand how stream systems and their fish populations respond to environmental changes.

I hope that in the last 3 days those of you working on Carnation Creek have been able to talk to some of the regional fisheries biologists and habitat protection people of the Fish and Wildlife Branch. Communication with the people who are in the management trenches is vital. They are the people for whom you're doing this work for at Carnation Creek. I think that ongoing communication between the researcher and resource manager is extremely important in ensuring that the correct direction of the study is maintained.

Finally, I want to comment on the confounding effects in the experimental design that were identified by previous speakers as occurring at the fence and the hydrological weir. Tom Chamberlain and I and others agonized over this problem in the original design of the study. Do you maintain accurate upstream-downstream fish counts and thereby perhaps confound the gravel conditions in the chum-spawning area below the fence? Do you gauge the stream with a hydrological weir and thereby create a possible confounding effect on the upstream migration of sculpins? In the experimental design, we chose to try and live with these confounding effects which Gordon Hartman now is saddled with unravelling.

The apparent demise of the trout in Carnation Creek was something that was flagged by Allen Edie and should be followed up. It may be related to just too many biologists and not enough trout. Carnation Creek does not provide very good trout habitat. I suspect that the populations were so low in the beginning that we may have handled many of those fish four times each while they were in fresh water.

The real graybeard on the effects of logging, of course, is Jim Hall, well known for his Alsea watershed work and other studies in Oregon. Jim has the reputation of being the authority on the effects of logging in western North America. It's a position that Gordon Hartman will probably occupy in another 5 years. I hope that Jim will share some of his experiences in Oregon, which, in many ways, parallel our Carnation Creek experience.

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Thank you very much. I must say that I feel a little uncomfortable in this role, speaking last, and evaluating, to a degree at least, the work that's been done here. I can remember back to the time 10 or 12 years ago when I spent a good deal of my effort trying to convince Dave Narver that he was all wrong in trying to set up another watershed study. I suggested that Carnation Creek wasn't the way to go and that he ought to try a large-scale, short-term synoptic survey. I suggested that he look at a lot of different watersheds over the whole west coast and maybe even into the interior. I must say that, after listening to the results of the last couple of days and reflecting a little bit on it, I'm going to have to eat some crow here publicly and say that I was wrong. I don't believe you could have accomplished what you have accomplished in this 10-year period if you had taken that synoptic approach at the beginning. That's not to say that there haven't been some problems, but I think they've been identified here and Gordon Hartman is aware of what some of those are. Perhaps he has ideas as to how to mitigate some of those problems. Some of them can't be avoided and you're just going to have to live with such problems because they are inherent to the design of a long-term watershed study. And I would also hasten to say that I still think that the synoptic approach is a good one and has some real advantages. I will say just a little bit more about that later on. As I reflect back on the Alsea watershed study, which began in 1957, I think it was a forerunner. However, when you compare the Alsea watershed study with Carnation Creek, it's pretty clear that Carnation Creek is the deluxe model—no question. Of course it should be a better study. You had a background to work on; you knew some of the problems that would exist. You were able to plan ahead to avoid some of them. But it is, I would judge, an order of magnitude more advanced and more productive than that original Alsea watershed study. The results are a real tribute to the hard work and close interaction of a large number of resource scientists and to some arm-twisting that has been done. My year in B.C. in 1971-1972 gave me a good view of the beginnings of the Carnation Creek study. I would like now to reflect on the general theme of the morning, "What do you need from this work?", "What did you get?"

Jim Walker stressed yesterday that one of the real contributions from such a study is simply getting a good working relationship among the people with different resource interests. You get each other's perspective, you understand each other's problems. That is one of the intangible benefits of this kind of project.

It is clear from the work we have heard that you also have a good deal of good science. A lot of terrestrial and aquatic ecology has been advanced by some of the very nice, detailed studies that have been done. You have also had some good integration of the work. Furthermore, you have gotten some visibility. That is important. The consumer and the clients will benefit from this work. Some of these benefits would not have come from a short-term study. At the risk of stepping on some toes, I have a few ideas that might help. I have four quick take-home messages regarding how you define impacts and what approaches are possible to help you.

First, how you apply this sort of information. Carnation Creek is one watershed, typical of some and not of others in the region. It is not like a lot of watersheds in British Columbia. You can't apply Carnation Creek results widely without some further analysis.

Now that you have identified a number of problems, you might take a broad scale, short-term view of these problems over a wide geographic region. As a supplement to Carnation Creek, tackle a specific problem—for example, windthrow. You could take 100 watersheds or cutting units with different aspect, slope, soil type, drainage, etc. You might then get a good prediction of when and where and how trees blow down and also whether that is good or bad. Those logs may be more valuable lying over the stream as cover for salmon and trout than if they were cut up into boards. That is a perspective that should be considered.

There are a number of different management problems like that one which can be successfully identified and dealt with synoptically. I am pleased to see the study on the Queen Charlotte Islands taking this broad approach. The Charlottes study and Carnation Creek will complement each other.

But even the Charlottes study will not be broad enough to cover all the types of management problems raised. Another part of the broader perspective that cannot be addressed in the Carnation Creek work is the question of downstream influence. Many small streams the size of Carnation Creek have impacts for downstream, e.g., downstream flow of debris or sediment. Temperature effects may have a large-scale cumulative effect over many years. Often the interpretation of intensive small-stream studies fails to take account of this sort of long-term cumulative effect. We need to add this perspective to the work that has already been done.

The last three ideas are not so well developed, but I would like to mention them. I don't have many answers but I have ideas about why some studies are necessary.

Watershed classification has already been addressed. The work that Tom Chamberlain is doing is leading to an approach that will allow better snyoptic work. You must use some system of classification to allow you to know what kinds of watersheds can be used as baseline for extrapolation.

Another kind of analysis that I am convinced of the need for, but I don't know how to do, is the development of a better system of habitat-quality indexing. How do you quantify habitat? How do you deal with interactions? e.g., What is the effect of the presence or absence of cutthroat trout on the way coho are using a particular habitat? This problem is one that is really in need of a lot of work. Some results are semipromising. But I have not seen much that I would really want to hang my hat on.

A final area that is important and noted in the Carnation Creek work is the idea that processes are an important thing on which to focus research effort. I would like to develop an example. There is an opportunity here to look at the way in which stream temperature is affected and how stream temperature affects the biological system. This may represent a really new perspective on the ways in which temperature is controlled and how it controls biological processes in a watershed. I realize that the results so far are very preliminary and that the model shown is empirical. But if it holds up, it suggests that, in a watershed like Carnation Creek, there are a different set of processes determining stream temperatures compared to some of the classical energy-budget models that were applied and successful in the Alsea study.

Here, there may be some different mechanisms. Perhaps total soil heating is important in determining stream temperature in watersheds such as those with shallow, rocky soils. I urge you to follow this up.

Having said all this and not being all that provocative, I am going to retreat back below the border. I will wish you well in continuing the study and certainly will be supportive as possible as you continue your results and the success you have achieved so far.

Fish, Debris, Vegetation, and Rate of Cut

Question *(R. Ptolemy)*: In looking at the Carnation Creek data, there are a number of questions which arise, in terms of an apparent increase in both the standing crop of coho in the summertime and related increases in smolt yield as a function of logging treatment. I think it would have been more appropriate to look at coho standing crop on a per-treatment basis and look at how that standing crop translates into smolt yield so that, in the more intensive treatments with a reduction in pool volume or rearing space or cross-sectional area and so on, that induced smolt weight and, therefore, smolt yield per kilogram had been reduced also as a function of the reduced amount of stable debris. Have you made any attempt, Gordon, to look at that aspect?

Answer *(G. Hartman)*: Well, at this stage, we have looked at it only as much as needed to determine the numbers of animals residing in the areas of different treatment and in the side channels. I think that, in part, the information that Peter presented really answers your question about the areas of intensive treatment where debris is unstable. Where there's less of it, there are fewer fish. And if you assume that habitat in other parts of the stream is occupied, those fish that get moved out, dislocated, in the early fall from the intensive treatment area are going to have to go down and go nose-to-nose with other fish that are already occupying the higher-quality habitat in other sections of the stream.

Comment *(J. Cederholm)*: I have a piece of information with me here from one of our students working on the Clearwater River; it might add some insight here. We have a stream, approximately one mile long, and we went through the stream and checked it off into about 1000-foot sections and branded the resident coho in each of these sections differently. The upper 1000-foot section, the top of the mile, was clearcut that year and it had all the positive benefits that everybody discussed that comes from solar inputs and so on and a lot of debris there in the summer which turned out to be quite unstable debris; however, it seemed to be quite beneficial that first summer and the fish, the coho, were using it quite heavily. So here's the stream, the upper end is clearcut, there's a lot of loose debris in the stream, and the coho populations were quite high, growing quite well. We had our first storm in the fall and all the fish or a very high proportion of those fish in that section were displaced down into the wooded area downstream. And we came back in our midwinter shocking and found that those brands just went boom, moved downstream. And we couldn't find hardly any fish up in the clear-cut area. That following spring, those fish contributed sizeably to the migration.

Question *(T. Harding)*: To follow up on the comments of Jeff Cederholm, you have, in fact, set up exactly the same thing that Jeff was describing, where you've got a controlled section with proper debris, banks, and cover at the bottom of the stream so you can set up the displacement situation in which the fish could be pushed down to the lower section, sit in good-quality habitat, and then smolt out in the spring. Have you noticed any proportional increase in the amount who are wintering in that area?

Answer *(G. Hartman)*: We only did winter observations in the one winter. We looked at the work that Dave Bustard did. It was just done differently, so we couldn't make comparisons (of our data and his) about the use of habitat in the lower part of the stream where there was a leave strip.

Comment *(T. Harding)*: I guess that it means that you have to have the results of smolt output. So if you log the stream carefully, with streambank protection in part of it, where overwinter survival may be high, extra survival in the good areas may mask the effect of logging.

Question *(Craig Wightman)*: There appears to be some evidence that those side channels or tributaries are receiving more recruits in the fall prior to the winter-flood period. How do you propose to address what the actual capacity of those areas are in terms of the expected smolt yield? Have you thought about how you might objectively assess what the carrying capacity of those tributaries may be.

Answer *(P. Tschaplinski)*: Yes, that's kind of like trying to estimate what the potential carrying capacity of the stream is. There's really very little way you can get a handle on that. All you can do is measure the standing stock of fish that occurs in the stream year after year. I think it is a valid point to raise, but I can't see how any convenient estimate could be made of the total potential that the areas can hold.

Comment *(G. Hartman)*: I think the carrying capacity is going to depend on the conditions that exist within those systems through the winter. I think that one could hypothesize conditions in Tributary 750 that might make for one level of carrying capacity, if you like, and hypothesize another set of conditions, under the same conditions of logging treatment, that make for another carrying capacity.

Comment *(G. Taylor)*: I'd like to comment on the answer about difficulty in estimating the total potential of the stream. Surely, the system is testable. You've got excess fry coming out of the system. They need that carrying capacity.

Answer *(G. Hartman)*: No, in earlier remarks, Blair said that it would be difficult to test the production section by section. It would require some sort of evaluation of population segments along the stream.

Comment *(B. Holtby)*: Everybody uses this term "carrying capacity" as if it meant something to somebody. It doesn't mean much to me. What is carrying capacity of a stream? Is it a thousand fish? Ten thousand fish?

Answer *(G. Taylor)*: Anytime you've got a surplus. You just go back and have a look at the ratio of inaudible.

Question *(Unidentified)*: How do you define "surplus"? Is it defined as the number of fish that leave the stream.

Answer *(G. Taylor)*: That's right.

Comment *(C. Scrivener)*: I didn't emphasize that in 1980 we looked at the densities. We have compared densities across all of the sections in that particular year. It's almost two-thirds above any of the other years. So if you're talking about the range of numbers in the spring in the prelogging period and before, we've got it understocked, under carrying capacity. If you're going to use that as a definition of "carrying capacity", we've had lower densities in all the sections this last summer.

Question *(E. Packee)*: Jeff, you spoke about the need for this large debris. And I'm concerned and have been concerned that, as we get into more and more intensive forest management, we just aren't going to have that big spruce. As an alternative, I've looked at the idea of cottonwood. Fast growing, we can grow cottonwood here at 100 years of age and have it 5 feet or better in diameter. I can't remember which river it is, down from the Bougachiel at the Cottonwood Campground. The cottonwood trees on that river were a major buffer for cutting. And I can still remember going there and watching, seeing these cottonwoods hanging in on the bank. Have you looked at cottonwood per se? What is your feeling toward cottonwood, with the idea of using it as a management tool for fisheries management or stream debris management?

Answer *(J. Cederholm)*: Yes, we are involved with cottonwood right at the moment, particularly on the Toutle River and up Mount St. Helen's area. We need something that grows rather fast there. I think that cottonwood has some benefits. I'm a little concerned about the breakdown rate of cottonwood. It's not quite as hard a wood as spruce, fir, hemlock. And I'm a little concerned about it's rotting rate. I don't know the correct term for that. In terms of providing large organic debris, it may have a short lifespan, particularly if it was exposed to the air for a length of time. You do find it along the rivers, it is large wood, and it grows fast. It might be useful during the interim in places like Mount St. Helen's, i.e., places that have been devastated already through logging or whatever. In these cases, it might be a consideration to use cottonwood. However, I am a strong believer in that "what is natural for that system is best for it". And so I really shy away from replacement of natural vegetation. If they're not playing that role in that stream basin, then what is playing the role you want to encourage in that basin, and that's the species you want to work on. But I wouldn't throw cottonwood out the window. There are some applications for it I think.

Question *(Unidentified)*: I wonder if, because we're talking primarily about Carnation Creek, we may not be overemphasizing the debris factor. It seems to me that, up coast (this may not apply to Carnation Creek where the soils are coarse, shallow, and stable) in the Charlottes and certainly in the midcoast where the soils are less stable, the problems are associated with sedimentation. When we talk about debris and about Carnation Creek, we're primarily concerned with a system that is for coho. In this situation we are trying to protect the coho's environment in the wintertime. On the other hand, in streams that are feeding into a lake where the major fish is sockeye, Are we going to be putting the same emphasis on debris in that system? or In this type of situation, should we not be putting more emphasis on sedimentation?

Answer *(J. Cederholm)*: I think that large organic debris is important everywhere. It is more important in some streams than in others. However, in most cases, it is a major part of the structuring that goes on in streams. But there are streams that are boulder stabilized, there are streams that are highly wood stabilized. But I think that it's pretty much a common need by streams coastwide. Now sedimentation is a problem—more so in some areas than in others. I think that, for instance, in the Charlottes, you may have more of a "mass soil movement" problem than one of sedimentation. In the Clearwater area, we have a sedimentation problem. They have it in Oregon, they have it in Idaho. And the wood is also a major consideration in those areas. Boulder streams tend to flush sediment faster; wood streams tend to be more stable if they have a good complement of wood. Unfortunately, it puts sediment and silt in storage. If there's more wood in the stream because they are stable, it takes longer to flush the sediments. So it's a thing where it has plusses and minusses to it. However, in most cases, stable stream can stand some silt. But if it gets some stability from the wood, it far overrides this. But the wood not only stabilizes but also provides a kind of cover and habitat that is so important to the rearing species, steelhead, cutthroat, coho, and the like.

Comment *(W. Young)*: I think you've hit a very good point about debris management—maybe the most important factor to look at in a stream such as Carnation Creek. There are other equally and maybe more important things to look at in other streams. The Charlottes are a good case where we have very unstable soils and mass-wasting problems.

Comment *(Unidentified)*: In areas where you don't have mass wasting, you've got, from what I've seen, probably more sedimentation coming from road problems than you do from within the main channel of the stream. In this particular case, the roads are removed from the stream, they don't have steep gradients, they're in thinner soils. In the streams where you've got road development in steep areas with hard-pan on the road surface, from what I've seen, more of the sedimentation is coming from the side roads. In this particular case, it seems like it's coming primarily from the main stream. So there's much more interaction with debris. It's not only providing a hiding spot for the winter coho and rearing areas for the trout but it's also providing the main source of sedimentation. I don't think that's the case in most coastal streams.

Comment *(W. Young)*: I guess what you're saying is how we interpret this data and extrapolate it is very important. I don't think any of us will disagree with that.

Comment *(J. Cederholm)*: I'd like to take this a step further, too. I've looked a lot at roads and I am very concerned about roads in a lot of basins. Probably the two biggest impacts that I've recognized from logging are the logging impact, the streamside and the upland management, and then the roads. Those are the two really big impacts that need attention. Some systems have both problems, some systems have one or the other. I've purposely stayed away from roads because they haven't come out as being a real big factor in this study. The factor that seems to be coming out in this study is the large organic debris. But that doesn't mean we shouldn't be paying strong attention to our road systems. Not only the placement of our roads but also the on-road erosion prevention that goes into that road construction.

Comment *(Unidentified)*: I'd just like to comment on mass wasting and debris. It appears to be a similar problem. Mass wasting in the Charlottes, from preliminary observations, seems to eliminate debris from the channel. In fact, we've got the same problem regarding large debris—just a different process. So I think it's quite common to almost all kinds of channels on the coast of British Columbia. It may be less of a question in sockeye spawning in creeks and lakes. I can't comment so much on that.

Question *(Unidentified)*: Right now I'd like to raise the question about the rate of cut. I think that is a major implication that may be coming out of Carnation Creek. We heard this morning, a couple of times, about 41% of the watershed being cut in 6 years with no real detectable impact in water flow. And, of course, this is qualified by the observation that it is not a snow watershed and the last years of logging have been mild years. I wonder if, in the future, we can look to any information on what the rain-on-snow effects might be, based on Carnation Creek results. I understand that this year we've had quite a bit of snow up there, and there has been a rain-on-snow event. So I'd like to ask Eugene or Charlie, or somebody who's had experience since the beginning, Were there snowy years in the early prelogging stages of Carnation Creek? Do you anticipate being able to make any suggestions for 6 or 7 years down the road about what the rain-on-snow impact might be in Carnation Creek?

Answer *(C. Scrivener)*: We have had rain-on-snow events there in January. We hope we'll have something to talk about in the near future, but they are totally unpredictable and they are rare in this type of system. We didn't have anything of this magnitude in the prelogging years. We had some snow at higher elevations and what appeared to be a number of storms where we have had higher water yield than we would have expected from the rainfall that came in on that particular storm. But that is only a limited number of freshets. You can count them on the fingers of one hand. To get a reliable picture from rain-on-snow events, you want a large collection of particular storms. It will take a lot of time to get that number of events out of a system like Carnation Creek. We could give a couple of answers maybe on the very few events that we have had, but that is about all.

Comment *(W. Young)*: I would like to make a little comment and perhaps make us all feel a little better as we grapple with this frustrating thing. In British Columbia along with the states just south of the line in the Pacific Northwest, I think we have unique challenges in resource management that exist nowhere else in the world. And I am told by my fishery biologists, for instance, that the Fraser River is the most important salmon river in the world. That has never been disputed. But in forestry, take the other major timber production areas, in the southeast states, which is a major timber production area, it is simple forestry. In this soil type, they plant one kind of pine, in that soil type, they plant another pine. That's all. In the Scandinavian countries, they've dammed all their salmon rivers. There are no salmon to be concerned about. They have spruce and pine and moose. That is all. In the countries like New Zealand and Australia, it is also a simplistic resource management situation. And I have had letters of support from scientists around saying that, in British Columbia and in the adjacent states, you have a unique challenge, you have an extremely important fishery resource, an extremely important timber resource, a very diverse wildlife resource, an aesthetic resource of high-quality, unstable soils in many areas and good timber. There is nowhere else in the world that can duplicate that and they are wishing us well in solving it. Because they are saying no one else is going to solve it for us. In other research areas, we can borrow, which we do, from Scandinavian research and from U.S. research. But, in the adjacent states and in British Columbia and Alaska, I think we have, and we are talking about it here, a unique problem. We probably have the most complex problem in integrating resource management there as anywhere that I've ever read. It may not solve anything, but it might make us feel better.

Comment *(E. Packee?)*: Following what you just said and having just been down in the south looking at some of this, I think you're 100% right. Where there's a problem in interpreting this, is this concept of multiple use. And multiple use was never conceived under its original idea that every acre had to produce something of this use, that use, and everything else. The concept behind multiple use was if you took a planning unit and you got the majority of the best uses out of that unit in the sense of multiple use where you could have two things, for example, forage for wildlife and trees for forestry. Fine. It dove-tailed—together you get one on top of the other. But in other cases, and the best one is a campground, you've got a scenic waterfall and all the rest of the stuff. You could take that out and say, "for this unit, this is the focal point for this part of the multiple-use problem". And I see exactly the same sort of thing for the fisheries (forestry recognizing that there are certain places); Riley Creek could be a very good example, where, when you look at all the problems that are tied to Riley Creek in the slide situation, maybe it wasn't a good place to go logging to begin with and we should have said, "this is primarily used for fish". We are looking at that. And there are other areas where streams are not highly productive and that we can turn around and say, "those areas we are looking at are primarily for fibre production". We have the problem when the question is, Which priority goes for which use? But I think it's very important to understand that the multiple-use concept was not conceived as having something of everything off of every hectare land. It was up to the management unit to get those best uses.

Comment *(Unidentified)*: The forest managers have indicated quite a lot of concern about getting some of these valley-bottom areas back into proper production, and talking about different experiments to analyze, what will happen when they feed it with chemicals and herbicides in order to get the suppression of salmonberry and alder, in particular. I'm wondering whether or not this study in Carnation Creek will point out that maybe higher groundwater levels have given an advantage to alder and salmonberry production methods. I'm wondering whether or not the forest managers are looking at alternative strategies in those areas. Maybe they can log the area in a manner so that the groundwater tables are not quite so high in the areas where they logged in the valley bottom or, alternatively, maybe they should consider managing those areas with follow-up plantings of deciduous seeds instead. I'm wondering if anybody from the Forest Service here or the forest industry might have a comment on that.

Answer *(P. Ackhurst)*: I don't think we are talking about experiments. We are at the point where it is an operational process where we plant spruce or cedar or whatever in these areas. If there is a water problem, then we tailor our species to those areas. We still treat those as our highly productive lands and that is where we want to grow our trees.

Question *(Unidentified)*: My point is, though, perhaps there's an ecological reason why salmonberry do so well there. And maybe that is in direct conflict with that production process.

Comment *(P. Ackhurst)*: We are also very impressed by how well the sitka spruce does there. These huge big trees were there—we cut them down in the first place. I think it's a question of the growth rates (of conifers) and their suppression, because the salmonberry and alder grow so fast, we just don't get the same growth coming out. It is not that it isn't a real good site for multi-class. (I may have this word wrong, Ed.) It's more of a question of what comes up the quickest and how we can deal with it.

Question *(Unidentified)*: (About large organic debris. Words not clear.)

Comment *(J. Cederholm)*: We have, in cooperation with the State Department of Fisheries. I have been involved in main-river coho-rearing studies and we're finding that, in a lot of our rivers, there's not a lot of large organic debris in the main rivers. Obviously, it's probably just washed away. But what is there is extremely important in physically stabilizing gravel bars, forming pools, forming ripples, creating meanders; but in terms of coho production, biologically, where you find coho is in the wood. You can almost point to where you can almost fly up the river and count the number of logjams in the main river and multiply them by a given number—that's how many coho are being produced out of the main river. So, I think that large organic debris in rivers is extremely important. I would even venture a guess to say that having it there may outweigh now having it in terms of coho production in main-stem rivers.

Road Construction

Question *(R. Murray (?))*: I have a general question. I came in this morning, so it may have been answered yesterday. A lot of these effects are frequently discussed in terms of road building. I haven't been to the project area. I was wondering where the roads are in Carnation Creek and how they have been looked at.

Answer *(C. Scrivener)*: We had a fairly large program here just before the first major road construction in the spring of 1975. That spring turned out to be really benign. We got some suspended sediment measurements coming locally from the small tributaries adjacent to construction. But one of the major aspects of this system is that the roads are pretty well all well up on the slopes. You have access in this sort of a system from three or four different locations. It is not like developing some watersheds where you start at the base and you have to gain elevation from there. Also, the stream meanders through the flat valley bottom. A lot of these tributary streams come down the slope and hit the valley bottom and disappear in summer-flow conditions. They disappear into the gravel of the valley bottoms. And under low-flow conditions, a lot of sediment gets trapped, or appears to get trapped, in the flats. In addition to this, it was mentioned by Eugene Hetherington and Ed Oswald that the soils are very shallow on one of the slopes. There's not really very much there to erode. We haven't observed any major impacts with road construction.

Question *(Unidentified)*: Would it be fair to suggest that Carnation Creek would then be more representative of logging practices in the absence of road building. It's got a pretty optimistic score in terms of logging effects on the fish.

Answer *(C. Scrivener)*: Well, we probably might have had quite a different situation if we'd had a different kind of spring for the initial road construction. The rest of the road construction is going on in slightly different locations—it's going on at the same time as the logging activity. I don't know how we can't separate those processes.

Comment *(D. Narver)*: There's nothing unusual about the road layout then, compared with other operations?

Answer *(C. Scrivener)*: No, not really, except that this watershed did have the advantage of access from a number of locations. And in a lot of other systems, the access is one direction and operators have to build a lot of roads to gain elevation. They didn't have to do that in this watershed.

Comment *(C. Scrivener)*: I just have one more comment to make about the road construction. In a lot of the areas where we have had problems in evaluating road construction impacts, there is a lot of side-cost material. A lot of the road construction in our system was simply just drill and blast. Very coarse material was laid down to form the roadbed. There was no trucking in or problems of getting rid of material or, where needed, finding material to produce the roadbed.

Question *(D. Toews)*: I would like to add a comment to Charlie Scrivener's information. We did some work in connection with some site-specific areas of construction that affected small trickles. We did get very, very high levels of sediment on site in the neighborhood. Our maximums were in the neighborhood of 10 000 mg/L. We followed that material downstream until it reached the main channel. You could see the turbidity disappearing at about 100 m. And in terms of a brief look at the data from B-weir, we could not pick up those pulses.

Forest Practices

Question *(C. Scrivener)*: I would like to bring up something we discussed very briefly. It is probably one of the issues over which we are going to be having a lot of controversy in the next few years. It deals with the business of streamside treatment and of stabilizing vegetation—alder being number one. It has already been indicated that, from the fisheries aspect, we need a little more effort toward understanding what the contribution of alder is to the stream, other than stabilizing banks. We need to understand better the importance of alder in providing food organisms for fish. We need to know more about the quality and fate of litter coming from alder. I would like to suggest a number of things, directed to the forestry aspect. One of the things that has become fairly known to us, from our association with the foresters, is the problem of good-quality stock for replanting prime valley-bottom sites that have brush problems. This shouldn't be taken as a direct criticism of the Forest Service at all, but I am wondering what has been looked into in regard to producing very large seedlings, a number of years old, to get an advantage over brush in these prime sites. I would also like to know if that area of nursery stock development is having serious problems with the budget cutback, problems that are likely to continue to occur over the next few years?

Answer ***(P. Ackhurst)*****:** Various kinds of stock are available. I don't know what the situation was in Carnation Creek, but we certainly do tailor larger stock to the high-quality site, brush-prone areas.

Question ***(C. Scrivener)*****:** But the understanding that I have is that there were some problems getting appropriate seedlings at a specific time of a good size. Are there real problems in providing nursery stock for these kinds of areas? I would think that this would be one of the areas–the number one area–in which you would be directing efforts for providing the best possible stock available and looking at some experimental opportunities for use of very large stock. Salmonberry only grows to a certain height. What about two-, three-, four-, or five-year-old stock in the planting process?

Answer ***(P. Ackhurst)*****:** There are no real technical problems to that. There might be some logistic problems.

Comment ***(J. Dryburgh)*****:** On the bottom-land areas, we have been planting three-year-old and, sometimes, two-year-old stock. There have been some logistical problems in getting three-year-old stock at times, but even so, this has not enabled us to get ahead of the brush in some of these sites that we have not been able to burn or scarify.

Comment ***(E. Packee)*****:** With respect to alder on the kinds of sites that we are talking about in Carnation Creek, if the alder gets established as much as 8 years after the plantation is established, the alder will take Douglas-fir and crowd it out. It grows extremely fast. I have seen it in the Kennedy Lake area, where it has overtaken plantations of Douglas-fir or spruce, and it has overtopped it, even though the spruce was 10 years old. With regard to salmonberry, a lot of these areas that I have been in have salmonberry that are 10 to 12 feet high. The only way you are going to get a species such as Douglas-fir through that is to have its nose through, and I just don't think it is logistically feasible to try to haul around Douglas-fir that size. We can switch species. In some cases, red cedar will make it through very nicely. In a lot of these areas (Carnation Creek is not one of them) where we have the salmonberry problem, we also have a thing called deer. If you go and plant Douglas-fir, a deer will follow right behind you and clean up the planting rows. This has been the case in Port Hardy and Port McNeil area. I have seen it in the Eve River, Kelsey Bay country. I've also seen it over on the lower mainland. So you have got one problem after the other.

Question ***(T. Harding)*****:** Just a question on the talk about salmonberry growth. I watched the slides on the first day. I almost thought that the slides suggested that, if you did not burn, you did not get as much growth of salmonberry and alder.

Answer ***(K. King)*****:** On the sites where the salmonberry has taken over, it was generally on unburned sites or lower wetland sites. With the exception of the lower slopes that did have burn on them, the burn was low intensity; the lower slopes were moist as well. Moisture appeared to be the important factor.

Comment ***(D. Morrison)*****:** I have a couple of comments and a recommendation to make for further research. Following on what Bill Young and (inaudible) said, that being cognizant of cost and cost per unit, I hope we are not going to look strictly at cost and cost per unit as the bottom line. I did not see your factors in there for social impacts. I will leave that at that. Both Dave Handley and Bill Young agree that, if guidelines are going to be rewritten, they should be done in group process so that everybody can be in agreement with them such that they can be applied in the field. But Dave, I have to ask you what is there in the current guidelines that you see as being a problem? I haven't seen you out walking the streams with us in the last few years. I wonder what your problems are, and whether you realize the problems that we have from our side. I can think of cases where we have asked for directional falling or special yarding to take place, in areas that are sort of "damned if you do" and "damned if you don't" situations. In these areas, you have critical streams and valuable trees. The system is either you leave the entire thing or you take all of the trees. Recognizing from Dave Toews' paper earlier in the meeting, how sensitive that upper site was, even to sensitively logged areas where the channel still became destabilized. I find that we are having real problems in sensitive areas in trying to have the companies come back with reasonable plans to apply directional falling, new methods of directional falling, or methods of yarding which can allow the timber to be extracted and yet minimize the impact on the stream. If there are some specific things in the guidelines you see lately, I'm not going back 4 or 5 years, I am referring to the last year or two, that needs applying in the field, then I think there is room to form a task force and work further towards that.

Comment *(D. Handley)*: I think one of the reasons that I proposed this was that there hasn't been a dialogue in a truly ——— situation. The parties have not all been involved. I may not have been out walking the banks, but mind you, other people have. What I look at, and maybe I see it through rose-colored glasses, is the work of the State of Washington and Oregon forest practices guidelines which were jointly developed, I understand by industry, by fishery biologists and I am not sure who all. The problems you are raising, I think, are really why I'm proposing to do something like this. We should have something that has been accepted by industry as a whole—not just something that you negotiate, for example, with Derek Ferguson or T. Mattice, just when you happened to be in their area. We don't have to reinvent the wheel every single time. I was asking around and as far as I can find out, there are no published guidelines at the moment, other than the 1974 ones, plus what is in the P-1 clause. If somebody can disabuse me of that fact and show that it has been accepted by everybody concerned, then I'll accept it. However, that is not what I've heard from Bill Young or Jim Walker or anybody else.

Comment *(D. Morrison)*: In the field, I'd like to think that we've evolved beyond what was put on paper to the point where we are looking at things site-specifically. I think the guidelines that we have have set a framework that we have progressed beyond site-specifically.

Comment *(P. Ackhurst)*: There seems to be a need for more discussion about streamside concerns. Doug, you and I have talked a few minutes ago about some more ideas about where the policies are and how they are to be put in—whether it is an advisory plan, a cutting permit, or a longer-term document; how the fisheries streamside management fits in with longer-term forest management in more than just at a logging phase.

Comment *(F. Boyd)*: Just a comment on revision of guidelines. It seems to me that either side of the fisheries-forestry discussion has a perception that the guidelines need reviewing. We had better review them and we had better review them together.

Question *(K. Moore)*: I have to say, I'm glad this topic has come up because I wanted to question Dave Handley about his earlier point. Several years ago, I spent a couple of years going around talking to people about streamside management guidelines and alternatives to guidelines, and I think what I'm getting from this Carnation Creek workshop is that the more that we understand stream processes the more we appreciate that different streams respond differently to different practices. The more we know about process the less able we are to come out with guidelines. I think that, if we want to develop a task force, your task force should be directed to communicating understanding and somehow try to get better decisions made in the field, rather than trying to develop a new set of guidelines.

(Comment requested from Jim Hall.)

Comment *(J. Hall)*: I can say just a bit about that. This year is the 10th anniversary of the Oregon Forest Practice Rules. In fact, I had the occasion to check with some of our environmental-quality folks just before coming up here to get their assessment of how this program has worked over the years. I think it's a general perception both amongst foresters and ecologists and also the environmental-quality unit (water quality) that this general approach is the way to go. It does require, again, very specific on-site restrictions that can't be written down word-for-word on specific management practices. To compare what's being done today with what was done 10 years ago, with the exception of one area, I think that it has worked and it has greatly improved the management of our stream and timber resources. The one area that is not satisfactorily dealt with by this specific approach of prescribing best management practices, rather than water-quality standards is the area of mass wastage or debris avalanches. That problem persists and, so far, has not been tractable by this specific approach. You can use the best damn management practices you want on a lot of our plans in the coast and you're going to lose them anyway. There is a real problem there which is really in need of some resolutions. That point reminds me of just one aside that I would like to put in relative to all the particular watershed studies and, for that matter, all the logging studies that I'm aware of, at least. I have sort of an uneasy feeling when I look at the results of both our study and this study here; that they really don't show a lot of specific problems. None of the work that has been done really addresses this question of how do mass wasting and debris avalanches affect specific fishery resources. All of those studies have been in areas where this has not been a problem, and I see this as really the major unsolved problem. In that respect, our scientific studies have not addressed that specific one. I hope that the Charlottes is going to be getting on to that specific problem. In any case, at least in Oregon, it works. That's not to say that it will work here. I did bring a few copies of the present revision of the forest practice rules, if anybody is interested.

Comment *(E. Packee)*: I would like to go back to this question of mitigation. I would like to approach it from two points. Hypothetically, if we had Carnation Creek as it was in 1976 before a road went in and we were not going to touch that watershed except to enhance the fish population. What would the fishery biologist do? I raise that question because I believe that there are some simple things that could be done. I am stealing from Bill Sheridan now, for example, locating gravel pits in areas where we are not allowed to locate right now, but in locations such that they could be utilized as rearing areas for salmonid. I have a gravel pitup in Deep (?) River. I swear that picture with the chainsaw shows what the fish did to get in there, because they are moving through the woods, through water that is filtering down during freshets. That gravel pit is full of fry right now. As a second possibility, what about "salt block" of nutrients? Could we turn around and put a slow-dissolving nutrient block in a stream and enhance the productivity at relatively low cost?

Comment *(G. Hartman)*: These are good comments. I think there are things that we know that could be done in a system like Carnation Creek. There would be logistic problems, but there are ways to enhance production.

Comment *(J. Cederholm)*: I would like just to add to what Jim Hall had to say about the states rules and regulations. They were promulgated in the mid-seventies, particularly specifically to protect water quality. There was really no knowledge of the role of large debris at that time. Rules were mainly for streamside protection and mainly addressed to sedimentation and temperature problems. We are finding out today and we feel that our laws need complete revision. Our poor practices and regulations need to be updated. I think that this needs to be an ongoing thing. I would encourage the groups that are concerned with this problem of streamside protection that you should always be meeting and upgrading your rules and regulations and your clauses as new information becomes available. We are going to be upgrading ours soon.

Question *(Unidentified)*: Have you any idea about the effect of commercial-fishery interception on the populations coming into Carnation Creek?

Answer *(G. Hartman)*: No, we don't have information on that now. It is difficult to get anything that would give us a good impression of the implications of fishing pressure on a little stock like that. Peter Tschaplinski nose-tagged a few hundred fish last autumn. But as far as I know, before that there was no numbered tagging.

Comment *(C. Scrivener)*: We tagged a few steelheads going down and, surprisingly enough, got 3 returned tags, all from different rivers—one from China Creek, one from Nahmint River, and one from Sarita River.

Question *(D. Morrison)*: On the topic of potential research, Where do we go from here? I'm wondering, with the number of hydrologists that are in the group, whether the rain-on-snow events that have occurred in Carnation have been studied? Maybe we need to look at these and see what can be generated from them. Also, I have another concern. I am on the Tsitika Follow-up Committee and one of the things that committee is charged with, is looking at a hydrology study, and I'm wondering whether there will be room to entertain the thought of doing some rain-on-snow work, if it was warranted, in some of the upper basins of the Tsitika watershed.

Comment *(E. Hetherington (?))*: If I might just comment on that, I think there is a Hydrology Subcommittee. One of the main thrusts of some of their research proposals is to work on rain-on-snow situations. The committee hasn't met for one year and a half or so, but it sees the need for such research.

Comment *(C. Scrivener)*: There might be some slight potential at Carnation Creek for study of rain-on-snow events. We have 7 years of background information on one of our control watersheds in elevations up to 2900 feet. The area is slated to undergo some logging towards termination of the Carnation Creek study. If somebody wished to take over something like that, we already have background material on flows available. You might get something there on rain-on-snow events. You would get one or two rain-on-snow storms on this small watershed every year.

Comment *(V. Poulin)*: Gordon, has there been frequent mention of mass wasting—It's a problem that didn't arise much at Carnation Creek. However, I want to point out, before people leave, that, in fact, the Ministry of Environment and the Forest Ministry have initiated a joint program on the Charlottes to look at the impact of landslides on fish habitat and forest sites. The program is not just restricted to identifying the impact of slides on habitats but also what could be done to improve stream situations following damage by slides. On four sites, we are looking at the prevention of erosion on slides and getting things back into production. There are a number of federal and provincial agencies participating in the program. There are also the people on contract in the program. It is a 4-year study and it is in its elementary stages.

ADJOURNMENT

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I would like, at the termination of this meeting, to say thanks for our 3-day session Chairmen—Dave Handley the first day, Jim Walker the second day, and Bill Young the third day. You, as an audience, have come here and participated with real enthusiasm. I wish to thank you and the working group people who have put in a major effort to get papers organized. My thanks to all of you. We have had a great deal of valuable feedback. I think that there has been a useful dialogue between people working in different resource sectors. I hope that they may understand each other a little better. This session certainly gives the Carnation Creek working group better insight into the kinds of things that managers are concerned with. Not only did the 5 panelists this morning help us a great deal in this regard, but in listening to the audience discussion, I think that we have benefitted even more. Thank you very much again. Maybe we'll see you again in about 4 or 5 more years for another meeting of this kind.

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